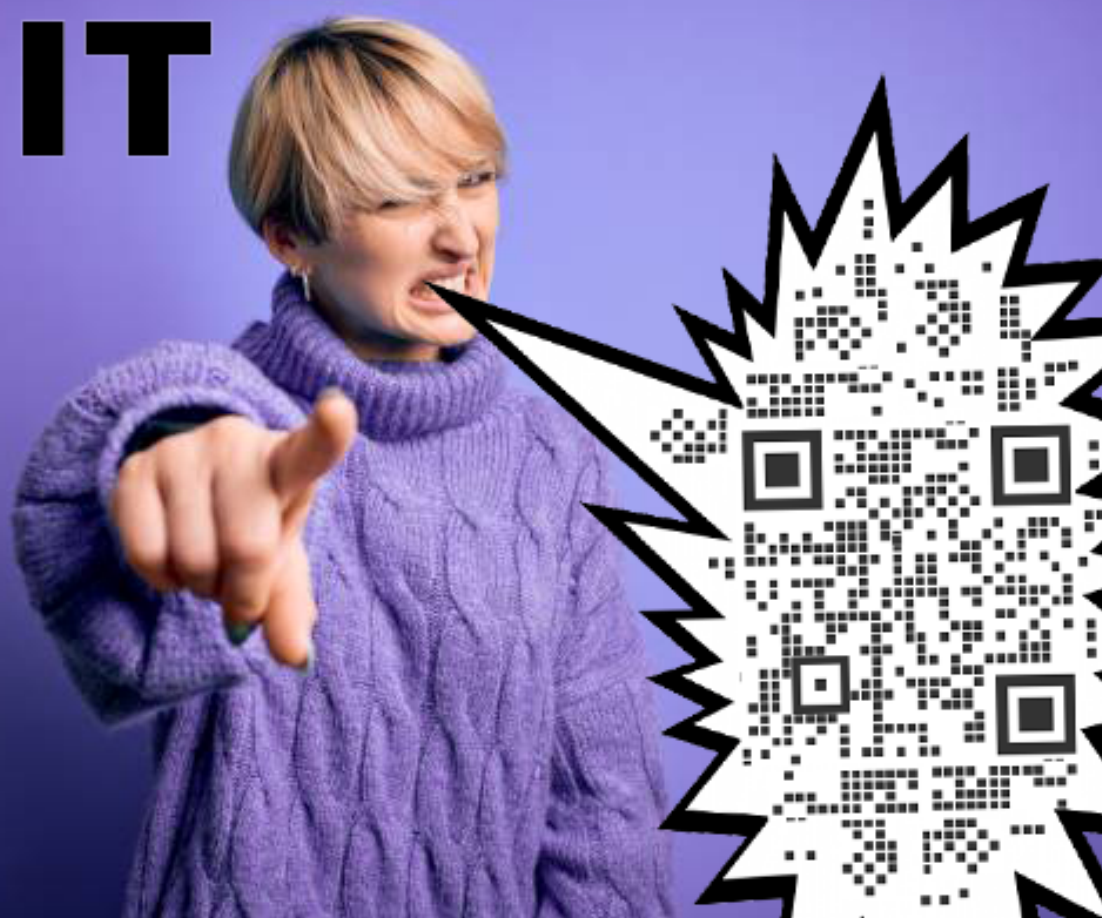


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Silurian Radiolarian Zonation
for the Caballos Novaculite,
Marathon Uplift, West Texas

by

Paula J. Noble

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TABLE OF CONTENTS

	Page
Abstract	5
Acknowledgments	5
Introduction	6
Regional Setting and Structural Framework	6
Caballos Novaculite	8
Sample Localities	9
Previous Work	9
Method of Sample Preparation	11
Effects of Preservation Bias	11
Radiolarian Zones of the Caballos Novaculite	11
Rotasphaerid Superzone (Ro)	13
Zone 1. <i>Palaeoactinosphaera</i> (?) <i>asymmetrica</i> Lowest Occurrence Zone	13
Zone 2. <i>Praespongocoelia</i> Taxon Range Zone	13
Zone 3. <i>Praespongocoelia</i> – <i>Stylosphaera</i> (?) <i>magnaspina</i> Partial Range Zone	13
Zone 4. <i>Stylosphaera</i> (?) <i>magnaspina</i> Taxon Range Zone	13
Zone 5. Rotasphaeracea– <i>Devoniglansus unicus</i> Partial Range Zone	13
Zone 6. <i>Devoniglansus unicus</i> – <i>Pseudospongoprimum</i> (?) <i>tauersi</i> Interval Zone	14
Chronostratigraphic Assignment	14
Comparison with Other Silurian Radiolarian Faunas	14
Southern Urals, Kazakhstan	14
Cornwallis Island, Canadian Archipelago	14
Japan	15
Kurosegawa Tectonic Zone	15
Assemblage 1. <i>Secuicollacta</i> ? <i>exquisita</i> Assemblage	15
Assemblage 2. <i>Pseudospongoprimum tazukawaensis</i> Assemblage	16
Assemblage 3. <i>Pseudospongoprimum sagittatum</i> Assemblage	16
Assemblage 4. <i>Devoniglansus unicus</i> Assemblage	16
Fukuji Area, Gifu Prefecture	16
<i>Fusalfanus osobudaniensis</i> Assemblage	16
<i>Praespongocoelia</i> (<i>Spongocoelia</i>) <i>parva</i> – <i>Praespongocoelia</i> (<i>Spongocoelia</i>) <i>kamitakarensis</i> Assemblage	16
<i>Zadrappolus yoshikiensis</i> Assemblage	16
<i>Stylosphaera</i> ? sp. A– <i>Stylosphaera</i> ? sp. B Assemblage	16
<i>Stylosphaera</i> ? sp. C Assemblage	17
Systematic Paleontology	17
Introduction	17
Radiolarian Species Concept	17
Morphological Terminology	18
Relationship Between the Rotasphaeridae and Pseudorotasphaeridae	18
Class Actinopoda	19
Subclass Radiolaria	19
Order Polycystida	19
Suborder Spumellariina	19
Superfamily Rotasphaeracea	19
Family Rotasphaeridae	19
Genus <i>Rotasphaera</i>	19
Genus <i>Secuicollacta</i>	22
Family Pseudorotasphaeridae	25
Genus <i>Pseudorotasphaera</i>	25
Superfamily Spongodiscacea	27
Family Sponguridae	27
Genus <i>Pseudospongoprimum</i>	28
Genus <i>Devoniglansus</i>	28
Superfamily Incertae sedis	29
Family Inaniguttidae	29
Genus <i>Inanihella</i>	30
Genus <i>Fusalfanus</i>	30
Genus <i>Oriundogutta</i>	31
Genus <i>Zadrappolus</i>	32
Family Palaeoactinosphaeridae	33
Genus <i>Palaeoactinosphaera</i>	33
Genus <i>Stylactinosphaera</i>	36

Family Palaeoscenidiidae	37
Genus <i>Goodbodium</i>	37
Genus <i>Holdsworthum</i>	37
Family Incertae Sedis	37
Genus <i>Bipylospongia</i>	37
Genus <i>Praespongocoelia</i>	38
Genus <i>Cenosphaera</i>	38
Genus <i>Stylosphaera</i>	39
Appendix: Radiolarian Sample Descriptions	39
References Cited	41
Plates	44
Index	53

LIST OF ILLUSTRATIONS

Text-figure	Page
1. Locality map for the Marathon uplift	6
2. Generalized stratigraphy of the Paleozoic Ouachita Front rocks exposed in the Marathon uplift	7
3. Locality map showing outcrop pattern of the Caballos Novaculite	7
4. Lithostratigraphy of the Caballos Novaculite west of the Dagger Flat Anticlinorium	8
5. Stratigraphic cross section of the lower chert and shale member of the Caballos Novaculite showing lithology and sample horizons	10
6. Radiolarian biozonation for the lower chert and shale member of the Caballos Novaculite showing ranges of primary and secondary marker taxa	12
7. Correlation of local radiolarian zones in the Marathon uplift with radiolarian assemblages described from Japan and Kazakhstan	15
8. Schematic diagram showing skeletal elements of the Rotasphaeridae	18
9. Schematic diagram showing skeletal elements of the Pseudorotasphaeridae	18
10. Schematic diagram of the genera in the family Inaniguttidae	29

LIST OF TABLES

Table	Page
1. Radiolarian taxon occurrence chart for the lower chert and shale member of the Caballos Novaculite	fold-out inside back cover)
2. Skeletal measurements for <i>Rotasphaera beckwithensis</i>	20
3. Skeletal measurements for <i>Rotasphaera delicata</i>	21
4. Skeletal measurements for <i>Rotasphaera marathonsensis</i>	21
5. Skeletal measurements for <i>Rotasphaera nuda</i>	21
6. Skeletal measurements for <i>Rotasphaera quadrata</i>	22
7. Skeletal measurements for <i>Rotasphaera robertsonum</i>	22
8. Skeletal measurements for <i>Secuicollacta cassa</i> ?	23
9. Skeletal measurements for <i>Secuicollacta foliaspinella</i>	24
10. Skeletal measurements for <i>Secuicollacta</i> (?) <i>platyspina</i>	24
11. Skeletal measurements for <i>Secuicollacta solara</i>	24
12. Skeletal measurements for <i>Pseudorotasphaera hispida</i>	26
13. Skeletal measurements for <i>Pseudorotasphaera communis</i>	26
14. Skeletal measurements for <i>Pseudorotasphaera lanceolata</i>	26
15. Skeletal measurements for <i>Pseudorotasphaera</i> (?) <i>robustispina</i>	27
16. Skeletal measurements for <i>Pseudorotasphaera</i> (?) <i>rotunda</i>	27
17. Skeletal measurements for <i>Pseudospongoprunum</i> (?) <i>tauersi</i>	28
18. Skeletal measurements for <i>Oriundogutta</i> (?) <i>kingi</i>	31
19. Skeletal measurements for <i>Oriundogutta</i> (?) <i>varispina</i>	32
20. Skeletal measurements for <i>Zadrappolus lunaris</i>	32
21. Skeletal measurements for <i>Palaeoactinosphaera antica</i>	34
22. Skeletal measurements for <i>Palaeoactinosphaera asymmetrica</i>	34
23. Skeletal measurements for <i>Palaeoactinosphaera barricki</i>	34
24. Skeletal measurements for <i>Palaeoactinosphaera</i> (?) <i>crucispina</i>	35
25. Skeletal measurements for <i>Palaeoactinosphaera elegantissima</i>	35
26. Skeletal measurements for <i>Palaeoactinosphaera</i> (?) <i>octaspina</i>	36
27. Skeletal measurements for <i>Stylactinosphaera prima</i>	36
28. Skeletal measurements for <i>Bipylospongia rudosa</i>	37
29. Skeletal measurements for <i>Praespongocoelia fusiformis</i>	38
30. Skeletal measurements for <i>Stylosphaera</i> (?) <i>magnaspina</i>	39

SILURIAN RADIOLARIAN ZONATION FOR THE CABALLOS NOVACULITE, MARATHON UPLIFT, WEST TEXAS

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ABSTRACT

This paper presents a local biozonation for Silurian radiolarians recovered from the Caballos Novaculite, Marathon uplift, Texas. Six measured sections representing 25–30 m of strata from the western half of the uplift have yielded abundant and moderately well-preserved radiolarian assemblages that can be subdivided into six biozones. The Rotasphaerid Superzone (Ro), contains the four oldest zones 1, 2, 3, and 4, and is defined by the first and last appearances of the superfamily Rotasphaeracea. The base of this superzone has not yet been determined in the Marathon uplift. All taxa chosen for this biozonation are commonly occurring, distinctive, robust forms that can be correlated from section to section, thereby meeting the criteria for establishing a practical and widely applicable biostratigraphic scheme.

Three conodont assemblages co-occur with the radiolarians and show the youngest zone to be no younger than Pridolian (Late Silurian). The oldest zone, Zone 1, is at least as old as Ludlovian and may be as old as Wenlockian (Early Silurian). Further chronostratigraphic calibration is needed to constrain the ages of these radiolarian zones better.

Taxa from the Ro Superzone bear strong resemblance to Silurian radiolarian assemblages from the Canadian Archipelago and Southern Urals, and are identical to forms described from the *Fusalfanus osobudaniensis* through *Stylosphaera* ? sp. C assemblages from the Fukuji Area, Gifu Prefecture, Japan. Several taxa in the lower part of Zone 6, above the Ro Superzone, are identical to those in the *Devoniglossus unicus* assemblage from the Kurosegawa Tectonic Zone, southwest Japan. The widespread geographic distribution of these assemblages suggests that it may be possible to generate a global radiolarian biozonation for the Silurian period.

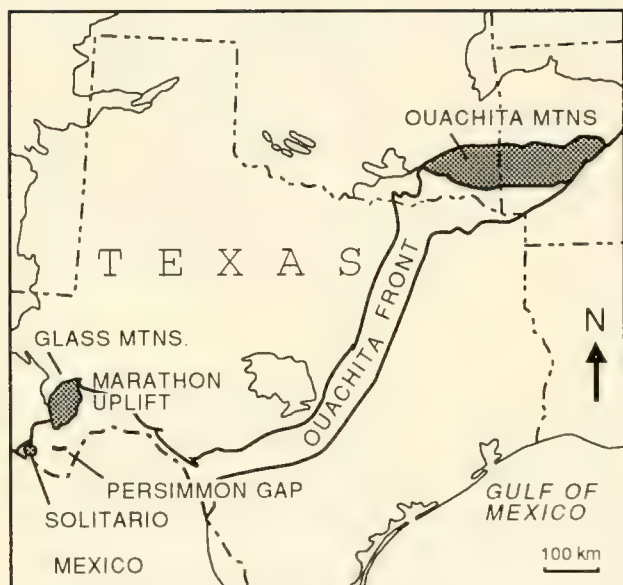
Various biostratigraphically useful Silurian radiolarians are described in this paper. One new superfamily, three new families, six new genera, and 28 new species are described. The new superfamily Rotasphaeracea includes the new families Rotasphaeridae and Pseudorotasphaeridae. Within the Rotasphaeridae are the genera *Rotasphaera*, n. gen. containing *R. beckwithensis*, n. sp., *R. delicata*, n. sp., *R. marathonsensis*, n. sp., *R. nuda*, n. sp., *R. quadrata*, n. sp., and *R. robertsorum*, n. sp., and *Secuicollacta* Nazarov and Ormiston, containing *S. cassa* ? Nazarov and Ormiston, *S. foliaspinella*, n. sp., *S. solara*, n. sp., and *S. (?) platyspina*, n. sp. Within the Pseudorotasphaeridae is *Pseudorotasphaera*, n. gen., containing *P. communis*, n. sp., *P. hispida*, n. sp., *P. lanceolata*, n. sp., *P. (?) robustispina*, n. sp., and *P. (?) rotunda*, n. sp. The new family Palaeoactinosphaeridae contains *Stylactinosphaera*, n. gen., with *S. prima*, n. sp., and *Palaeoactinosphaera*, n. gen. containing *P. antica*, n. sp., *P. asymmetrica*, n. sp., *P. barricki*, n. sp., *P. (?) crucispina*, n. sp., *P. elegantissima*, n. sp., and *P. (?) octaspina*, n. sp. Other new taxa described are *Pseudospongoprimum* (?) *taueri* n. sp., *Praespongocoelia* n. gen., containing *P. fusiformis*, n. sp. and *P. parva* Furutani, *Bipylospongia*, n. gen. containing *B. rudosa*, n. sp., *Stylosphaera* (?) *magnaspina*, n. sp., *Oriundogutta* (?) *kingi*, n. sp., *Oriundogutta* (?) *varispina*, n. sp., and *Zadrappolus lunaris*, n. sp. Systematic revisions of the following taxa also are included: Genus *Secuicollacta* Nazarov and Ormiston and its type species, *Secuicollacta cassa*, Family Inaniguttidae Nazarov and Ormiston and its genera *Inanigutta* Nazarov and Ormiston, *Inanihella* Nazarov and Ormiston, *Fusalfanus* Furutani, *Zadrappolus* Furutani, and *Oriundogutta* Nazarov and Ormiston, in addition to *Spongocoelia parvus* Furutani, *Fusalfanus osobudaniensis* Furutani, and *Pseudospongoprimum*, Wakamatsu et al.

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finance a visit to Nagoya University for the study of the type Silurian radiolarians deposited by Dr. H. Furutani and Mr. H. Wakamatsu. I am greatly indebted to Drs. S. Mizutani and S. Kojima and to Mr. K. Sugiyama and Ms. H. Nagai of Nagoya University for their assistance with the collections. I thank Jim Hayne and Ike Roberts of the Paisano Cattle Company, Travis and Polly Roberts of the Roberts Ranch, Gage Holland, Ann, and Mark Daugherty of the Gage Ranch, and Bob McKnight for permitting access to field areas. This manuscript was greatly improved by the comments and criticisms provided by the reviewers, Jon C. Aitchison and Charles D. Blome. I also thank Richard E. Casey, Martin B. Lagoe, Brian K. Holdsworth, William R. Muehlberger, and Emile A. Pessagno, Jr.

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Text-figure 1.—Locality map for the Marathon uplift showing its position at the southwestern extent of the Ouachita Front, Big Bend region, west Texas. Shaded area denotes outcrop areas of the Ouachita Front.

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INTRODUCTION

Paleozoic radiolarian studies is a relatively young field that has grown over the last decade into a dynamic area of research with valuable biostratigraphic and paleoecologic application (Jones and Murchey, 1986). In the early 1980's, biozonal schemes were first introduced for Late Devonian and younger rocks (Holdsworth and Jones, 1980; Ishiga *et al.*, 1982). Since that time, an increasing number of detailed Late Paleozoic radiolarian studies have been published (e.g., Won, 1983; Nazarov and Ormiston, 1985; Cheng, 1986). In contrast, early Paleozoic radiolarians have remained relatively unstudied, with the ranges of taxa uncertain and poorly dated. As a consequence, there are large gaps in the existing Paleozoic biozonations and no comprehensive radiolarian zonation exists for the Silurian through Middle Devonian.

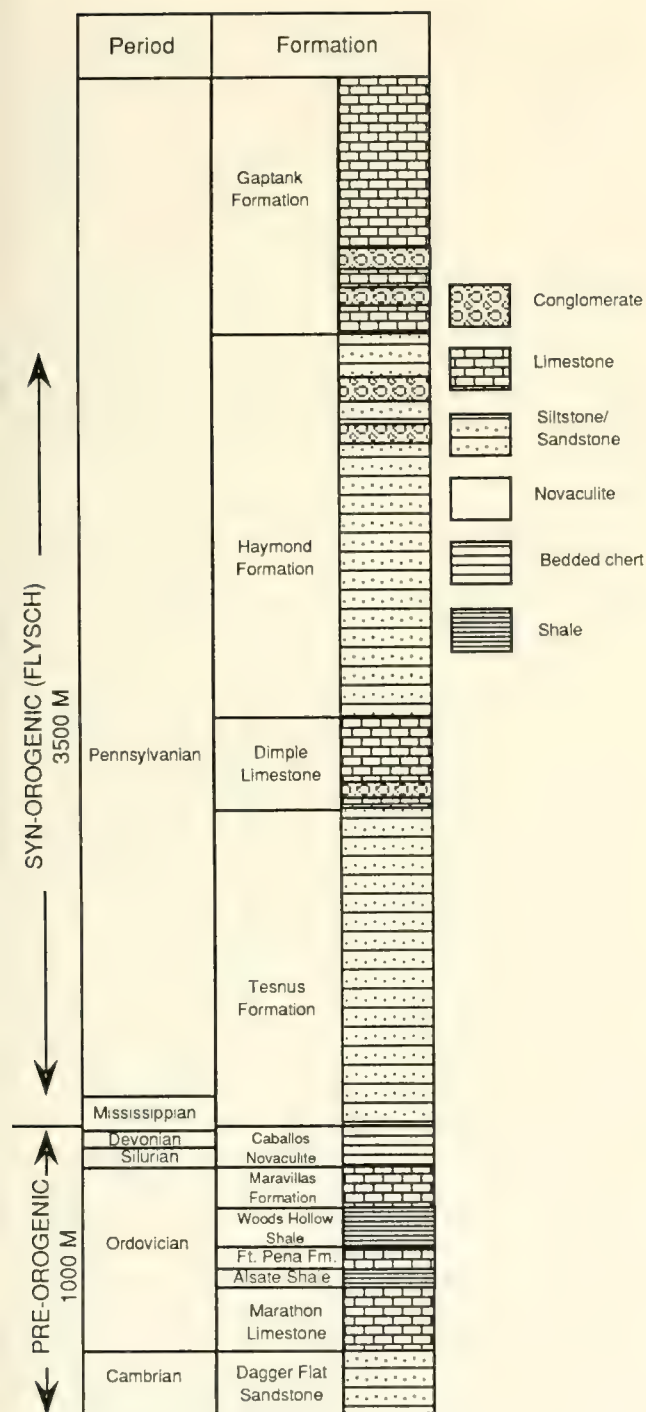
The few published works on Silurian radiolarians have documented unique and diverse assemblages which show potential for generating a useful biostratigraphic scheme for the early Paleozoic. Silurian radiolarians have been described from Japan (Furutani, 1990; Wakamatsu *et al.*, 1990; Aitchison, 1991), Australia (Aitchison, 1990), the Canadian Archipelago (Goodbody, 1986; Renz, 1988), and Kazakhstan (Nazarov, 1975). Several workers have been able to place their assemblages in a stratigraphic context, yet a num-

ber of the studies are detailed accounts of taxa from isolated samples, or samples collected from poorly exposed and faulted sections. Although these studies are good surveys of the potential diversity of early Paleozoic faunas, they provide limited biostratigraphic information. The data presented herein from the Marathon uplift are critical to the development of a comprehensive early Paleozoic biostratigraphic scheme because they have been collected from a number of structurally continuous measured sections where stratigraphic relationships between radiolarian assemblages can be recognized.

REGIONAL SETTING AND STRUCTURAL FRAMEWORK

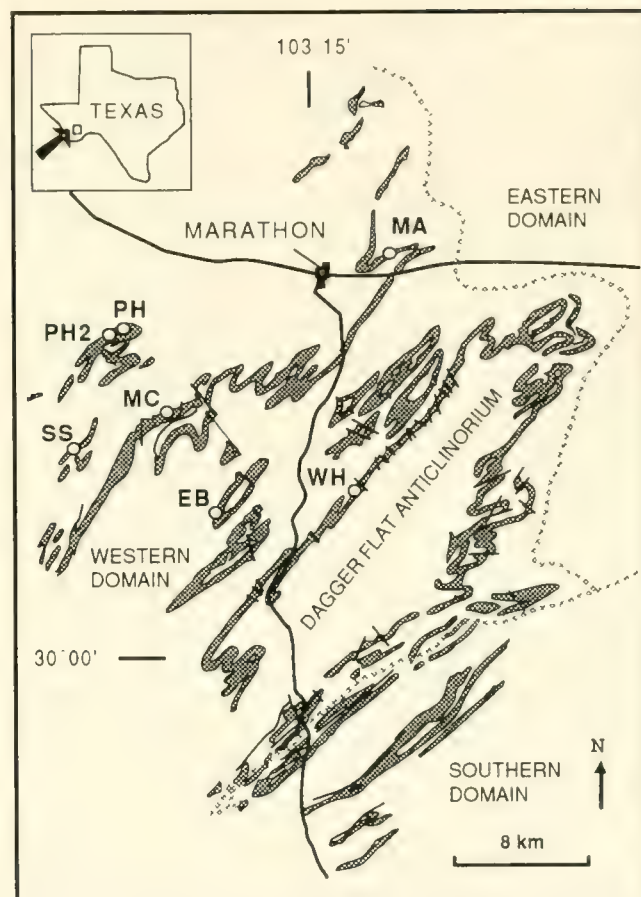
The Marathon uplift exposes deformed Cambrian through Pennsylvanian marine sedimentary strata believed to have been deposited in a parautochthonous basin located along the rifted southern paleocontinental margin of North America (Arbenz, 1989). These rocks are exposed in a topographic depression, the 3500 square km Marathon Basin, located approximately 50 km north of Big Bend National Park (McBride, 1989). The basin is rimmed by Cretaceous carbonates to the east, south, and west, and by the Permian Glass Mountains to the north-northwest. The Marathon uplift is part of a larger feature, the Ouachita orogenic belt, a sinuous, mainly subsurface belt that extends from the Big Bend Region of Trans-Pecos Texas to east-central Mississippi (Flawn *et al.*, 1969; Text-figure 1). The Ouachita orogenic belt was deformed synchronously with the Appalachian System in the Carboniferous-Permian Ouachita orogenic phase caused by the convergence of proto-North America (Laurasia) with Gondwana (Ross, 1979). Rocks of the Ouachita orogenic belt crop out only in the Marathon uplift, Persimmon Gap area, and Solitario uplifts of west Texas, and in the Ouachita Mountains of Oklahoma and Arkansas.

Two stages of deposition are recognized in the Marathon uplift on the basis of sediment composition and rate of deposition; a slowly deposited pre-orogenic stage and a more rapidly deposited syn-orogenic (flysch) stage (Thomson and McBride, 1964). The rocks deposited during the pre-orogenic stage are Cambrian-earliest Mississippian and are characterized by extremely low rates of deposition producing approximately 1000 m of shales, chert, limestone, and minor sandstone over a 200 million year period (Text-figure 2). The syn-orogenic stage, starting in the late Mississippian, is characterized by high rates of deposition producing a thick clastic wedge of approximately 4000 m thickness deposited in only 60 million years (McBride, 1989). Paleocurrent indicators and overall geometry of the syn-orogenic strata indicate that the dominant source



Text-figure 2.—Generalized stratigraphy of Paleozoic Ouachita Front rocks exposed in the Marathon uplift. The pre-orogenic sequence was deposited along a rifted passive margin, whereas the flysch sequence was deposited syn-orogenically during the Ouachita orogeny.

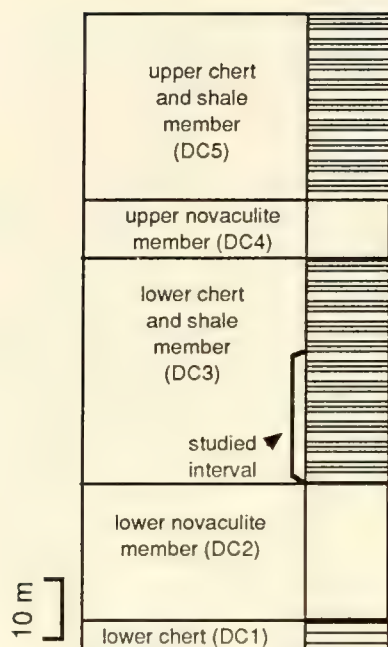
of terrigenous clastic debris, in particular, the source for the Tesnus and lower Haymond, came from the southeast (McBride, 1966; Cotera, 1969). Some of the clastic input during the syn-orogenic stage, however, did come from the north and northwest. A northern



Text-figure 3.—Locality map showing outcrop pattern of the Caballos Novaculite in gray, modified from King (1937). Heavy gray dotted line separates structural domains of Muehlberger (1978). Measured sections: PH = Payne Hills, PH2 = Payne Hills II, SS = Sulphur Springs, MC = Monument Creek, MA = McKnight, EB = East Bourland, WH = Wood Hollow. See Appendix for the precise location of each section.

source is proposed for the Dimple Limestone, a calcarenite sandwiched in between the Tesnus and Haymond formations (Thomson and Thomasson, 1969), and olistostromal blocks that occur in the base of the Tesnus Formation in the western basin margin can be traced to North America (McBride, 1978). The size of the Tesnus olistoliths also indicates that the basin had to be in close proximity to continental North America to allow for their transport.

The rocks exposed in the Marathon uplift have been folded and thrust into a series of anticlinoria-synclinoria and imbricate stacks of thrust sheets trending NE and showing transport to the NW (King, 1937; Flawn *et al.*, 1961). The structural grain is well illustrated by the outcrop pattern of the Caballos Novaculite (Text-figure 3). Three structural domains are recognized in the uplift based on the deformational style and the rheology of the rocks exposed (Muehlberger, 1978; Muehlberger and Tauvers, 1989). The western



Text-figure 4.—Lithostratigraphy of the Caballos Novaculite west of the Dagger Flat Anticlinorium. Unit abbreviations follow McBride and Thomson, 1970. See Text-figure 2 for an explanation of the lithologic symbols.

domain is characterized by exposures of tightly-folded, pre-orogenic strata overlain by a thin (1000 m) sequence of syn-orogenic strata, whereas the eastern domain exposes thick (3000 to 5200 m) sequences of broadly-folded syn-orogenic strata. The southern domain consists of imbricate stacks of thrust sheets, composed principally of syn-orogenic strata. Within the western domain, Muehlberger and others have been able to estimate degree of structural shortening; the strata west of the Dagger Flat Anticlinorium have been shortened by approximately 2:1 and the Dagger Flat Anticlinorium has been shortened by as much as 6.2:1 (Coley, 1987; Muehlberger 1990, 1991).

CABALLOS NOVACULITE

The Caballos Novaculite is the youngest unit deposited during the pre-orogenic stage. It is a highly condensed biosiliceous unit that is underlain by the Late Ordovician Maravillas Limestone and overlain by the late Mississippian to Pennsylvanian Tesnus Formation. The formation is lenticular in shape with a maximum thickness of 210 m but generally ranges between 65 and 150 m (McBride and Thomson, 1970). The Caballos Novaculite is subdivided into five members, each consisting of one of two lithologies; medium-bedded spiculitic novaculite and rhythmically bedded chert and shale (Text-figure 4). The novaculite members are commonly milky-white, highly resistant, bench-and ridge-forming units. Both the lower and up-

per novaculite members vary in thickness and in some areas are entirely absent. Their characteristic white color is derived from the near absence of clay or impurities (Folk, 1965; McBride and Thomson, 1970). The chert and shale members are slightly less resistant than the novaculite, forming slopes and ridges. They consist of rhythmically bedded varicolored chert, shale, and porcelainite that contain varying amounts of clay, iron oxides and other impurities. The chief biogenous components in the chert and shale members are radiolarians, although some spiculitic beds occur. The uppermost member becomes progressively shalier up section and grades into the lower olive to black colored shales and siltstones of the Tesnus Formation.

The recovery of Silurian radiolarians and conodonts provides important biostratigraphic control for the Caballos Novaculite. Until recently, the Caballos had yielded only a small amount of biostratigraphically useful information, chiefly in the form of conodonts recovered from the uppermost member of the formation (Graves, 1952; Barrick, 1987). The lower half remained undated and it was unclear whether the Silurian was present at the base of the Caballos in condensed form (e.g., Thomson and McBride, 1964; McGlasson, 1967), or if it was missing, cut out at a disconformity at the Maravillas–Caballos boundary (e.g., Baker and Bowman, 1917; King, 1937). The biostratigraphic data presented herein answers this long-standing question by providing the first documentation of Silurian strata in the Marathon uplift. Silurian conodonts and radiolarians recovered from the lower chert and shale member show that half of the formation is Silurian. The Caballos Novaculite is therefore shown to be a long-lived record of siliceous sedimentation, uninterrupted by significant pulses of clastic input, that spans from the Silurian through the earliest Mississippian, a period of over 70 Ma.

The improved age control afforded by radiolarians and conodonts makes several important contributions to the regional geology. First, it allows the members of the Caballos to be correlated more precisely to Silurian–Devonian North American continental shelf deposits in the subsurface of west Texas (Noble and Barrick, 1991; Noble, 1993a) and in doing so, helps to provide a clearer picture of the Silurian–Devonian depositional history along the southern paleo-continental margin of North America. Second, understanding the relationship between shelf and basinal facies may help answer questions concerning the environment of deposition of the Caballos Novaculite. The factors controlling deposition of the novaculite members has been a subject of considerable interest and debate; interpretations have ranged from deposition in a peritidal setting (e.g., Folk, 1973; McBride and Folk, 1977) to deposition in a deep marine setting (e.g., Thomson, 1964;

McBride and Thomson, 1970; Folk and McBride, 1976; McBride and Folk, 1977). Work in progress that combines detailed biostratigraphy with sedimentology and paleoecology may shed further light on this subject. Third, the biozones have the potential to aid greatly in the structural interpretation of complex parts of the basin where stratigraphic relations have been obscured by folding and faulting. For example, the absence of the lower novaculite member in parts of the Payne Hills at the western basin margin has been previously interpreted to be caused by structural attenuation (McBride, 1978). Biostratigraphy of the areas in question show that the absence of the lower novaculite is not structurally controlled but caused by a facies pinch-out of the lower novaculite (Noble and Barrick, 1991; Noble, 1993b). Further fine-tuning of these biozones and calibration with chronostratigraphic data will create a powerful tool which can be applied to understand better the structural styles and depositional history of the Marathon uplift during the Silurian–Devonian.

SAMPLE LOCALITIES

The data set for this study comes from seven measured sections of the basal 10 to 25 m of the lower chert and shale member of the Caballos Novaculite. These sections were chosen for their stratigraphic continuity and completeness. Additional sections were sampled during the reconnaissance process but are not included in this report because of their structural complexity and uncertain stratigraphic position. All sections occur in the western part of the uplift, westward of the Dagger Flat Anticlinorium (Text-figure 3). Little data were recovered eastward of the west limb of the Dagger Flat Anticlinorium (ridge containing WH section), due in part to poor exposure and poor fossil recovery, and in part to lack of access to private property. Radiolarians are sufficiently abundant, distinctive, and well-preserved to allow for the recognition of six biozones which can be traced from section to section across the basin. All biozones described occur within a minimum of two measured sections. Locality and sample descriptions are found in the Appendix.

Samples were collected during six field excursions conducted from November of 1987 through September of 1990. A reconnaissance trip in November of 1987 determined that fossiliferous samples could not be recognized reliably in the field. Whereas radiolarians are sometimes visible in the field with the aid of a 14× hand lens and appear as glassy spheres, radiolarians in the Caballos samples are seldom visible. Some glassy spheres were observed in hand specimen, but laboratory work later identified them as cristobalitic lepispheres, not fossils. Other samples that appeared to be barren of radiolarians in the field produced well-preserved specimens when processed in the lab.

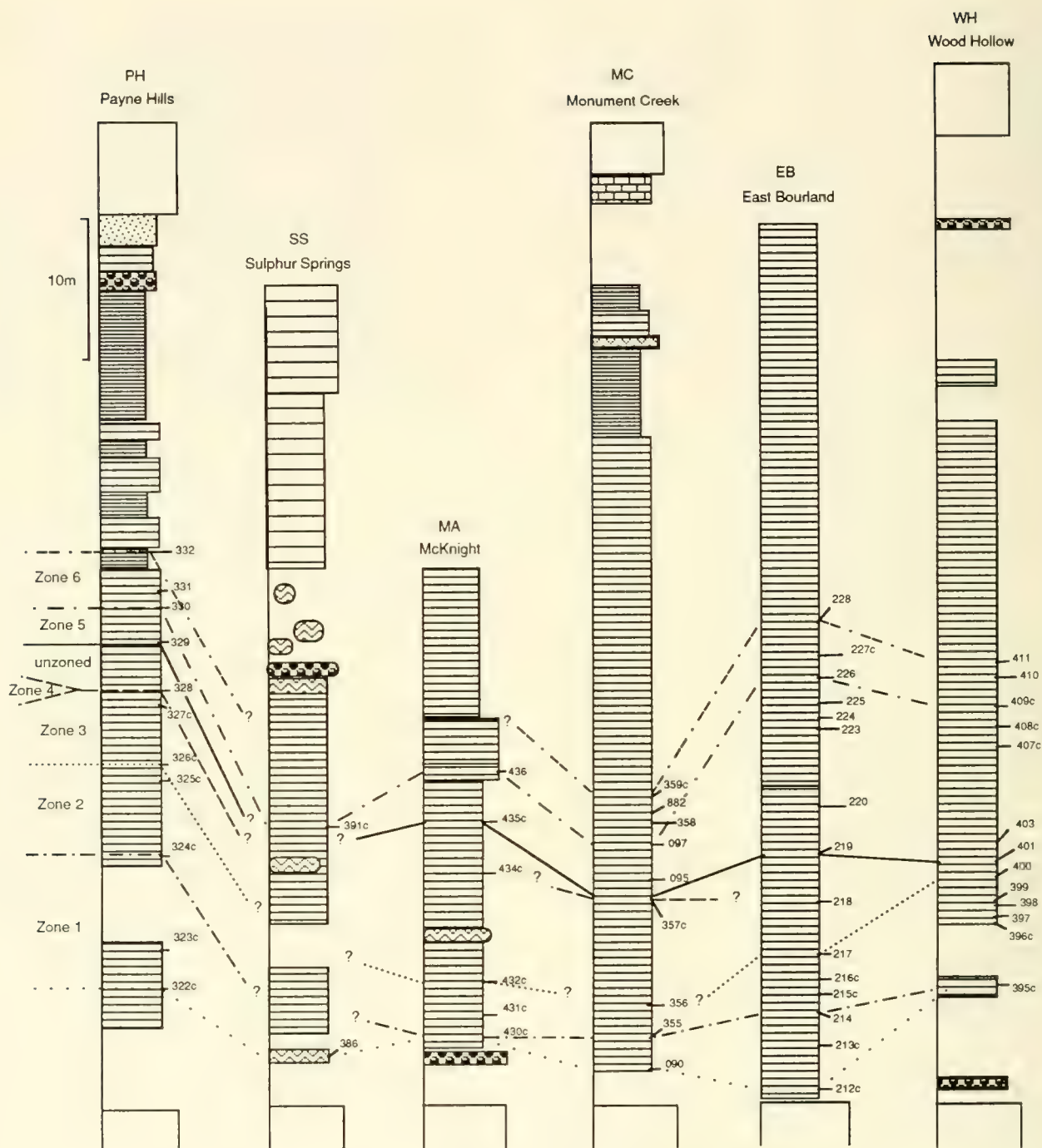
Since fossils could not be observed in the field, a variety of sampling strategies were employed to maximize fossil recovery. Some sections were sampled in great detail on a bed-by-bed basis over several meter intervals (e.g., Payne Hills II section) and other sections were sampled by collecting composite samples of two to four adjacent beds at 50 cm intervals to increase chances of recovery. Composite samples are indicated by a “c” following the sample number (Text-figure 5). Some of the productive sections that were sampled by the composite method were later re-sampled for single bed samples (e.g., Monument Creek). Access to parts of the field area became restricted in 1989 and limited the amount of re-sampling. Limited access was allowed for a finite number of excursions in 1990, during which I focused on collecting from unsampled and under-sampled localities.

Composite sampling, while necessary to insure fossil recovery, is potentially problematic because it may condense two or more temporally distinct assemblages into one sample. If composite assemblages combine strata equivalent to a long time interval they can artificially extend stratigraphic ranges and may falsely portray an overlap of ranges for taxa that do not actually overlap in time. Composite sampling effectively reduces the resolution of the data set and limits the degree of biostratigraphic subdivision possible. Despite the fact that half of the samples are composites, the lower chert and shale can be finely subdivided and successfully correlated biostratigraphically. Should future access be permitted, additional re-sampling by the single-bed method can be used to test further for the mixing of assemblages in composite samples and may serve to allow for an even greater degree of biostratigraphic resolution.

PREVIOUS WORK

Aberdeen (1940) described 32 new species of radiolarians from thin-sections of the Caballos Novaculite. The studied material came from two samples collected by P. B. King from the Santiago Member of the Caballos Novaculite. The Santiago Member originally referred to the rhythmically bedded chert and shale that overlies the novaculite. The name Santiago Member is no longer in use, since it has been demonstrated that two distinct novaculite horizons exist throughout much of the basin. Aberdeen provides no precise locality information, but based on the forms illustrated in her work, the samples appear to be from the lower half of the lower chert and shale, within the Rotasphaerid Superzone.

It is difficult to incorporate Aberdeen's taxonomic scheme into the one employed in this paper. Aberdeen's taxa were described entirely from cross-sectional views in thin-section, and many are not recog-



Fossil occurrence datums:

- | | | | |
|--|-------------------|--|------------------|
| | Novaculite | | Arenaceous chert |
| | Bedded chert | | Limestone |
| | Wavy bedded chert | | Conglomerate |
| | Shale | | |

- | | |
|--|--|
| | LA <i>Pseudospongoprimum tauversi</i> |
| | FA <i>Devonglansus unicus</i> |
| | LA <i>Rotasphaeracea</i> |
| | FA & LA <i>Stylosphaera (?) magnaspina</i> |
| | LA <i>Praespongocoelia</i> |
| | FA <i>Praespongocoelia</i> |
| | FA <i>Palaeocactinsphaera asymmetrica</i> |

nizable in matrix-free samples. The cross-sectional view of radiolarians seen in her thin-sections is inadequate for descriptive taxonomy, as it provides no view of surface textures and does not allow for the determination of the number and symmetry of spines. Aberdeen's type specimens from the Caballos were examined by Riedel and Foreman (1961) who more accurately located each type specimen in thin-section with the aid of an England Finder, a gridded 3" × 1" glass slide divided into 1 mm squares. Riedel and Foreman noted the relative abundance of all taxa that they were able to locate and provided useful sketches of several taxa they observed in thin-section. Wherever possible, Aberdeen's taxa have been incorporated into the taxonomic scheme presented here. Synonymies are discussed for those taxa which can be reliably determined to be conspecific with the taxa described herein.

METHOD OF SAMPLE PREPARATION

All samples were recovered from radiolarian cherts by etching in dilute hydrofluoric acid for a 24 hour period (Pessagno and Newport, 1972). Individual radiolarians liberated from the matrix by the dilute etching were washed and sieved at 63 and 108 micron fractions. Some samples were cleaned by heating in 30% hydrogen peroxide for five minutes. The hydrogen peroxide bath proved destructive to specimens in the less well-preserved samples and was only used when necessary on well-preserved faunas. Radiolarians were picked from dried residues and identified with the aid of reflected light, transmitted light, and scanning electron photomicroscopy. All photos were taken using a Jeol JSM-T330A scanning electron microscope and a Nikon polarizing microscope with photomicrographic attachment. Measurements were made with the aid of an objective micrometer mounted in the ocular of a Wild reflected-light microscope.

EFFECTS OF PRESERVATION BIAS

Radiolarian assemblages recovered from the Caballos Novaculite are preservationally biased towards the more robust forms. Typically, radiolarian assemblages extracted from siliceous lithologies have a strong preservational bias because of the diagenetic effects of chertification and the destructive chemical extraction technique that employs hydrofluoric acid to liberate the fossils from the siliceous matrix (Blome and Reed,

1993). Radiolarians extracted from limestones and carbonate or phosphatic concretions are generally much better preserved than those recovered from siliceous rocks (Blome and Albert, 1985; Blome and Reed, 1993), yet volumetrically, most Paleozoic radiolarians occur in siliceous lithologies such as porcellanites, cherts, siliceous mudstones, or argillites. Some delicate spicular taxa characteristic of well-preserved Silurian assemblages recovered from limestones and concretions are rare in the Caballos samples, and because of their sporadic occurrence, are not used as marker taxa in this biozonal scheme.

An important consideration in erecting any biostratigraphic scheme is its applicability. The radiolarian biozonation presented herein is designed specifically for use on siliceous rocks. All taxa chosen are robust, distinctive, common, and short-ranging, thereby meeting the requirements for practical application to siliceous rock units. Their potential application to calcareous rocks or phosphatic concretions is untested and may be limited, however, because of the marked differences caused by differential preservation.

Preservational biases may also play a significant role in how the taxonomic framework is initially erected. Internal structure and wall construction are two characteristics which are considered to be critical in determining the phylogenetic relationships of Spumellariina (Pessagno, 1977). It is often difficult to analyze the internal structures when working with chert residues. Radiolarians are frequently filled with microcrystalline quartz or chalcedony which obliterates the delicate internal structure (Pl. 4, fig. 5) and only rarely, are the internal structures preserved. Considerable attempts have been made to find specimens that have the internal structure preserved. Wherever possible, reflected light microscopy has been used to illustrate these features better (Plates 8, 9). Quite frequently, the internal structure is reflected in external features, such as in the number and symmetry of spines. Taxa whose internal structures could not be determined have been provisionally classified at higher taxonomic levels using other external/skeletal characteristics.

RADIOLARIAN ZONES OF THE CABALLOS NOVACULITE

A number of biohorizons, defined by either the first or last appearance (FA or LA) of a distinct and robust taxon, have proven useful in biostratigraphic correla-

←
Text-figure 5.—Stratigraphic cross section of the lower chert and shale member of the Caballos Novaculite showing lithology and sample horizons. Samples with a "c" following the number are composite samples of 2 or 3 adjacent beds within a 30 to 130 cm interval. Lines of correlation are the radiolarian biohorizons (first and last appearance datums) used to construct the local biozonation. Cross section is hung on the base of the lower chert and shale member. See Text-figure 3 for location of individual measured sections.

ZONE NUMBER	BIOZONE	ABBREV.	PRIMARY MARKER TAXA	SECONDARY MARKER TAXA
6 *	<i>Devoniglansus unicus</i> - <i>Pseudospongoprunum</i> (?) <i>tauversi</i>	Du - Pt	<i>D. unicus</i> ↑ ↓ <i>P. (?) tauversi</i>	<i>O. (?) varispina</i> ↓ ↑ <i>Z. lunaris</i>
5	<i>Devoniglansus unicus</i> - <i>Rotasphaera</i>	Ro - Du		<i>Z. tenuis</i> ↑
4	Rotasphaerid Superzone (Ro)	<i>Stylosphaera</i> (?) <i>magnaspina</i>	↑ ↓ <i>St. (?) magnaspina</i>	↑ Spumellarian indet. sp. A
3 *		<i>Praespongocoelia</i> - <i>Stylosphaera</i> (?) <i>magnaspina</i>	↑	↑ <i>Z. yoshikiensis</i>
2		<i>Praespongocoelia</i>	↑ <i>Praespongocoelia</i>	↑
1		<i>Palaeoactinosphaera</i> <i>asymmetrica</i>	↑ <i>P. asymmetrica</i> Rotasphaeraea	↑ <i>B. rudosa</i> ↑ <i>P. (?) crucispina</i> ↑ <i>F. osobudaniensis</i> ↑ <i>S. prima</i>

Text-figure 6.—Radiolarian biozonation for the lower chert and shale member of the Caballos Novaculite showing ranges of primary and secondary marker taxa. Relative abundances are shown for selected marker taxa. Asterisk (*) denotes the stratigraphic position of conodont samples 1 and 2. Shaded area represents an unzoned interval.

tion of the lower chert and shale. Seven of these biohorizons are used to define the bases and tops of six radiolarian zones (Text-figure 5). At present, the radiolarian biozonation presented herein is strictly a local correlation tool designed to biostratigraphically correlate the lower chert and shale with the most useful and reliable criteria available. It has not been tested outside of the Marathon uplift in order to determine if there are stratigraphic gaps or variations in taxa distribution. As further data on Late Silurian radiolarians is gathered, the zonal scheme presented herein can be compared to other locally devised zonal schemes in order to build a comprehensive Silurian radiolarian biozonation with geographically widespread application.

All zones are defined in accordance with the International Guide to Stratigraphic Nomenclature (ISSC, 1976; ISSC in press). Two of the zones are taxon range zones and four of the zones are types of interval zones. Principle marker taxa used in defining each zone appear in Text-figure 6 along with secondary marker taxa. The occurrence of all taxa described in this paper can be found in Table 1. The basis for the chronostratigraphic calibration of these zones is discussed in the section entitled Chronostratigraphic Assignment. The definitions of the types of zones used herein, as defined by the ISSC (in press), are as follows:

Taxon Range Zone.—The body of strata representing the known range of occurrence of specimens of a particular taxon.

Interval Zone.—The body of fossiliferous strata between two specified biohorizons. The base or top of an interval zone may be the lowest occurrence of a taxon, the uppermost occurrence of a taxon, or any other distinctive biostratigraphic feature (biohorizon).

Lowest-Occurrence Zone.—An interval zone representing the strata between the lowest occurrences of two specified taxa.

Partial Range Zone.—An interval zone that partitions the range of a taxon so that the base is defined by the uppermost occurrence of one taxon and the top is defined by the lowermost occurrence of a second taxon; the ranges of the boundary taxa do not overlap. The name for a Partial Range Zone may be derived from the names of the boundary taxa or from the name of the taxon whose range was partitioned.

The use of interval zones whose identification relies on the absence of distinctive taxa is controversial. A Partial Range Zone is one such zone that is distinguished from underlying and overlying taxa by the absence of the boundary taxa. Absences are not always

a reliable means of correlation because they can be controlled by preservation and paleoecologic constraints. Two Partial Range Zones are used herein because they are believed to be the most useful means of biostratigraphic subdivision for the interval of study. The boundary taxa for these Partial Range Zones have been chosen specifically because they are first and last occurrences of robust, commonly occurring taxa. These taxa are sufficiently robust so that they would be less affected by preservational biases than most other taxa with which they co-occur. They are the most distinctive and easily identified biohorizons recognized in the lower chert and shale and are the most useful criteria available for biostratigraphic correlation.

ROTASPHAERID SUPERZONE (Ro)

This zone is defined by the presence of the Rotasphaeracea. The base of this zone is not recognized in the Marathon uplift. The top is defined by the last appearance of members of the Rotasphaeracea. Four biozones can be recognized within the Rotasphaerid Superzone; two taxon range zones, and two interval zones (Text-figure 6).

Zone 1: *Palaeoactinosphaera* (?) *asymmetrica* Lowest Occurrence Zone (Pa) (Equivalent to Ro1 Zone of Noble and Barrick, 1991)

The base of this zone is defined by the first appearance of *Palaeoactinosphaera* (?) *asymmetrica*, n. sp. The top is defined by the first appearance of *Praespongocoelia*, n. gen. Taxa that are common but not restricted to this zone are *Palaeoactinosphaera* (?) *crucispina*, n. sp., *Bipylospongia rudosa*, n. sp., *Stylactinosphaera prima*, n. sp., *Pseudorotasphaera hispida*, n. sp., *Pseudorotasphaera lanceolata*, n. sp., and *Fusalfanus osobudaniensis* Furutani, 1990. The upper part of this zone is distinguished from the lower part of Marathon uplift Zone 2 only by the absence of *Praespongocoelia*.

Age: Silurian (Wenlockian–Ludlovian)

Zone 2: *Praespongocoelia* Taxon Range Zone (Pr) (Equivalent to Ro2 of Noble and Barrick, 1991)

The base and top of this zone are defined by the first and last appearance of the genus *Praespongocoelia*. Three species of *Praespongocoelia* occur within the zone, two of which are described in this paper; *P. parva* Furutani, 1990 and *P. fusiforma*, n. sp. *Fusalfanus osobudaniensis*, *Palaeoactinosphaera* (?) *crucispina*, *Bipylospongia rudosa*, and *Stylactinosphaera prima* make their last appearance in the lower part of this zone, and *Palaeoactinosphaera* (?) *octaspina*, n. sp. makes its first appearance towards the top of this zone. Other taxa which are common, but not necessarily restricted to this zone, include *Palaeoactinosphaera*

elegantissima, n. sp., *Pseudorotasphaera* (?) *robustispina*, n. sp., *Rotasphaera marathonensis*, n. sp., *Palaeoactinosphaera barricki*, n. sp., *Rotasphaera beckwithensis*, n. sp., *Pseudorotasphaera hispida*, n. sp., and *Pseudorotasphaera* (?) *rotunda*, n. sp.

Age: Silurian (Wenlockian–Ludlovian)

Zone 3: *Praespongocoelia*–*Stylosphaera* (?) *magnaspina* Partial Range Zone (Pr–Sm)

This zone represents a portion of the range of the Rotasphaeracea. Its base is defined by the last appearance of *Praespongocoelia* and the top by the first appearance of *Stylosphaera* (?) *magnaspina*, n. sp. *Zadrappolus tenuis* Furutani, 1990 makes its first appearance near the base of this zone and becomes very abundant at the top. Many of the taxa occurring in this interval occur in both underlying and overlying zones. Common taxa include abundant *Rotasphaera* and *Pseudorotasphaera*, such as *R. quadrata*, n. sp. and *Ps. communis*, n. sp., and a progressive increase towards the top of the zone in the abundance of Inaniguttidae, particularly *Zadrappolus* Furutani, 1990.

Age: Silurian (Wenlockian–Ludlovian)

Zone 4: *Stylosphaera* (?) *magnaspina* Taxon Range Zone (Sm) (Equivalent to Ro3 of Noble and Barrick, 1991)

The base and top of this zone are defined by the first and last appearance respectively, of *Stylosphaera* (?) *magnaspina*. Also present is a three spined spumellarian (listed in Table 1 as Spumellarian indet. sp. A) and abundant Inaniguttidae, such as *Oriundogutta* (?) *kingi*, n. sp. and *Zadrappolus tenuis*. *Rotasphaera* and *Pseudorotasphaera* are present but are an insignificant part of the assemblage. This interval is very thin and is represented by only two samples in the Marathon uplift.

Age: Late Silurian (Ludlovian–Pridolian)

The following zones overlie the Rotasphaerid Superzone:

Zone 5: Rotasphaeracea–*Devoniglansus unicus* Partial Range Zone (Ro–Du)

This zone represents a portion of the range of the genus *Zadrappolus*. The base is defined by the last appearance of the Rotasphaeridacea and the top is defined by the first appearance of *Devoniglansus unicus* Wakamatsu et al., 1990. This zone includes abundant Inaniguttidae, such as *Oriundogutta* Nazarov, 1988, *Zadrappolus yoshikiensis* Furutani, 1990, *Zadrappolus tenuis* Furutani, 1990, *Zadrappolus* cf. *Z. spinosus* Furutani, 1990, and spongy Spumellariina (Pl. 5, figs. 13, 14) of uncertain affinity.

Age: Late Silurian (Ludlovian–Pridolian)

Zone 6:

Devoniglansus unicus–*Pseudospongoprimum* (?)
tauersi

Interval Zone (Du)

(Equivalent to PRo1 and PRo2 combined of
Noble and Barrick, 1991)

The base of this zone is defined by the first appearance of *Devoniglansus unicus* Wakamatsu et al., 1990 and the top is defined by the last appearance of *Pseudospongoprimum* (?) *tauersi*, n. sp. *Pseudospongoprimum* (?) *tauersi* makes its first appearance near the base of the zone and *D. unicus* makes its last appearance in the middle of the zone. Other characteristic taxa include *Oriundogutta* (?) *varispina*, n. sp., *Zadrappolus lunaris*, n. sp., and *Zadrappolus* spp.

Age: Late Silurian (Ludlovian–Pridolian)

CHRONOSTRATIGRAPHIC ASSIGNMENT

It is rare to find other biostratigraphically useful fossils co-occurring with radiolarians in Paleozoic siliceous sequences. In the Caballos Novaculite, conodonts and radiolarians co-occur in the same sample in rare instances, and provide the only means of independent chronostratigraphic calibration. As a consequence, the chronostratigraphic assignment for the described radiolarian zones is crude. It is based on calibration with three conodont assemblages and by comparison with other documented occurrences of Silurian radiolarians (Text-figure 5). Conodonts were found to co-occur in abundance with three radiolarian-bearing samples collected in the vicinity of the Monument Creek section by Dr. Jim Barrick of Texas Tech University. All conodont identifications were made by Dr. Barrick (Noble and Barrick, in prep.). Sample residues were mailed to me for radiolarian identification.

Conodont sample 1 occurs in Zone 3, the *Praespongocoelia*–*Stylosphaera* (?) *magnaspina* Zone, and is interpreted to be Wenlockian–Ludlovian based on the presence of *Dapsilodus praecipuus* Barrick, 1977, *D. sparsus* Barrick, 1977, *Walliserodus* sp. indet., and *Kockelella absidata* Barrick and Klapper, 1976. Radiolarians identified in this sample are *Cenosphaera hexagonalis* Aberdeen, 1940, *Zadrappolus spinosus* Furutani, 1990, *Rotasphaera beckwithensis*, n. sp., *Secuicollecta solara*, n. sp., and *Pseudorotasphaera* sp. indet.

Conodont sample 2 occurs at the top of Zone 6, the *Devoniglansus unicus*–*Pseudospongoprimum* (?) *tauersi* zone, and is interpreted to be Ludlovian–Pridolian based on the occurrence of *Ozarkodina eostein-hornensis* ?, *Belodella* sp. indet., and *Dapsilodus obliquicostatus* Bransen and Mehl, 1933. Radiolarians identified in this sample are *Cenosphaera hexagonalis* Aberdeen, 1940, abundant *Oriundogutta* (?) *varispina*,

n. sp., rare *Pseudospongoprimum* (?) *tauersi* and *Palaeoactinosphaera* (?) *octaspina* ?.

Conodont sample 3 occurs several meters above the top of Zone 6 and is interpreted as Pridolian based on the presence of *Dapsilodus obliquicostatus* and a species of *Belodella* possessing a “fan” which is formed by denticles on the side of the cusp.

COMPARISON WITH OTHER
SILURIAN RADIOLARIAN FAUNAS

Several detailed works describe Silurian radiolarians from Kazakhstan, Japan, and the Canadian Archipelago. A comparison of each of these faunal assemblages to the Caballos Novaculite assemblages follows and a preliminary correlation appears in Text-figure 7.

SOUTHERN URALS, KAZAKHSTAN

Nazarov (Nazarov, 1975, 1988; Nazarov and Ormiston, 1984) described radiolarians from lower Ludlovian multicolored shales and cherts along the Sakmara River that contained *Oriundogutta* (?) *kingi*, n. sp. (identified as *Inanihella macroacantha* Rüst, 1892) and *Secuicollecta cassa* (Nazarov and Ormiston, 1984). Both *S. cassa* and *Oriundogutta* (?) *kingi* occur within the *Rotasphaera* Superzone of the Marathon uplift. The Urals material is not extensively figured and only a preliminary comparison can be made (Text-figure 7). Chronostratigraphic assignment of this section to the Ludlovian is based on the graptolites *Monograptus marri* Perner, *Peltalograptus tenuis* (Barrande), and *Streptograptus* sp. indet. which were identified by T. N. Korenj (Nazarov, 1975).

CORNWALLIS ISLAND, CANADIAN ARCHIPELAGO

Radiolarians have been recovered from micritic graptolite-bearing limestones of Llandoveryan–Wenlockian age (Holdsworth, 1977; Goodbody, 1986, 1988; Renz, 1990). Accurate age control is based on graptolites and conodonts. Multiple samples from measured sections have been recovered and show an exceptionally well-preserved fauna rich in rotasphaerids, undescribed Palaeoactinommids, and delicate spicular Palaeosceniids. In addition to the rotasphaerids, the Cornwallis Island material have *Cenosphaera hexagonalis* Aberdeen, 1940, and *Goodbodium* Furutani, 1990 in common with the Marathon uplift material. No forms resembling *Praespongocoelia* n. gen. or *Bi-pylospongia* n. gen. have been recovered from Cornwallis Island. Their absence may be explained: 1) by a possible older age for the Cornwallis Island material, or 2) by paleoecologically controlled distribution of the robust spongy taxa. Estimates of paleogeographic reconstructions place Cornwallis Island approximately 30 degrees north of the Marathon uplift (Scotese and

This Paper		Furutani, 1990, Japan	Wakamatsu et al, 1990, Japan	Nazarov, 1988, Kazakhstan	EPOCH	PERIOD		
<i>D. unicus</i> - <i>P. (?) tauversi</i>			<i>P. sagittatum</i>		Pridoli	LATE SILURIAN		
			<i>D. unicus</i>					
Rotasphaeracea - <i>D. unicus</i>								
Rotasphaerid Superzone (Ro)		<i>Stylosphaera</i> ? sp. C & <i>S.?</i> sp A - <i>S.?</i> sp. B			? — ?		Ludlow	
	<i>S. (?) magnaspina</i>							
	<i>Praespongocoelia</i> - <i>S. (?) magnaspina</i>							<i>Z.yoshikiensis</i>
	<i>Praespongocoelia</i>	<i>S.parvus</i> - <i>S. kamitakarensis</i>	<i>P. tazukawaensis</i>					
	<i>P. asymmetrica</i>	<i>Fusulfanus osobudaniensis</i>	<i>S.? exquisita</i>	<i>I. tarangulica</i> - <i>S. cassa</i>	? — ?			
					Wenlock		EARLY SILURIAN	
					Llandovery			

Text-figure 7 — Correlation of local radiolarian zones in the Marathon uplift with radiolarian assemblages described from Japan and Kazakhstan.

McKerrow, 1990), so both possibilities are equally likely.

JAPAN

By far, the most extensive work on Silurian radiolarians appears in studies by Wakamatsu et al. (1990) and Furutani (1990) from two regions in Japan. Radiolarians have been recovered from measured sections of partially dismembered siliceous and tuffaceous shale sequences from the Kurosegawa Tectonic Zone (Wakamatsu et al., 1990) in southwestern Japan, and from the Fukuji Area, Gifu Prefecture, central Japan (Furutani, 1990). Local radiolarian assemblages were described for each region and are discussed below.

Kurosegawa Tectonic Zone

Four distinct assemblages described by Wakamatsu et al. (1990) are interpreted to be of Silurian age. Structural dismemberment of the Kurosegawa sections and poor chronostratigraphic control have made the stratigraphic relationships between assemblages difficult to interpret. The *Devoniglans unicus* assemblage has been interpreted to be younger than the *Pseudospongoprimum sagittatum* assemblage (Wakamatsu et al., 1990), yet comparison with the stratigraphically intact

assemblages of the Marathon uplift indicates that the *P. sagittatum* assemblage may be younger than *D. unicus* assemblage (Text-figure 7). A description of the four assemblages and correlation to the Marathon biozones follows.

Assemblage 1. Secuicollacta ? exquisita Assemblage. — This assemblage is poorly preserved and only a few taxa are described, none of which are particularly diagnostic. It contains *Secuicollacta exquisita* Wakamatsu et al., 1990, a poorly preserved rotasphaerid with 10 or more rod-shaped primary spines and remnants of secondary spines, and a specimen of *Goodbodium*. Based on the presence of *Secuicollacta*, this assemblage occurs within the Rotasphaerid Superzone. The absence of inaniguttids, such as *Zadrappolus* spp., and *Praespongocoelia* spp. suggests that it may possibly be equivalent to Zone 1 of the Marathon uplift or older. Whereas absences of taxa are not always reliable as a means for biostratigraphic correlation, the *Zadrappolus* spp. and *Praespongocoelia* spp. are robust taxa that survive in poorly preserved samples at least as well as the rotasphaerids. It is doubtful that their absence would be controlled by preservational bias. Furthermore, these *Zadrappolus* and *Praespongocoelia* are not unknown from the Kurosegawa tectonic zone. Wa-

kamatsu *et al.* (1990) reports them from other samples in the area, making a strong case for this sample to be correlative to Marathon uplift Zone 1 or older. Assemblage 1 comes from the G2 Formation which is reported as being of late Llandoveryan to Wenlockian age, based on trilobites and conodonts.

Assemblage 2. Pseudospongoprimum tazukawaensis Assemblage.—This assemblage contains rotasphaerids and *Pseudospongoprimum tazukawaensis* Wakamatsu *et al.*, 1990 which may be conspecific with *Praespongocoelia parva* Furutani, 1990 (see systematic description). At present, this assemblage is tentatively correlated to the middle part of the Marathon uplift Zone 2, the *Praespongocoelia* Zone, and is limited to those horizons containing *P. parva*. The age of this assemblage is reported as middle Wenlockian–middle Ludlovian, based on corals, conodonts, and trilobites.

Assemblage 3. Pseudospongoprimum sagittatum Assemblage.—This assemblage contains *Pseudospongoprimum sagittatum* Wakamatsu *et al.*, 1990 and a variety of non-rotasphaerid Spumellariina. *Pseudospongoprimum sagittatum* is similar to *Pseudospongoprimum (?) tauversi*, n. sp. and the presence of the non-rotasphaerid Spumellarians in the *P. sagittatum* assemblage is consistent with the interpretation that they are the same assemblage. (See the species description of *P. (?) tauversi* for a detailed comparison of the two taxa.) There is no age control for this assemblage other than that stratigraphically, it falls between Upper Silurian and Middle Devonian strata. If this assemblage is equivalent to the *P. (?) tauversi* Zone, then the age can be determined as Late Silurian based on the conodont control in Marathon uplift.

Assemblage 4. Devoniglansus unicus Assemblage.—This assemblage is low in diversity and contains *Devoniglansus unicus* as well as *Helioentactinia ? prismspinosa* Wakamatsu *et al.*, 1990. First-hand examination of type material from this assemblage shows it to be equivalent to the *D. unicus* Assemblage in the Marathon uplift. *Helioentactinia ? prismspinosa* has the same cortical wall structure as *Inanigutta* and because the authors could not discern an internal spicule within the medullary shell, they tentatively placed it in the genus *Helioentactinia* Nazarov, 1975. This species also co-occurs in the *D. unicus* assemblage in the Marathon uplift. There is no age control for this assemblage in Japan, yet the authors have presumed it to be Early Devonian based on its dissimilarity with other described Silurian faunas. Conodonts indicate the age of *D. unicus* is no younger than Pridolian (Late Silurian) in Zone 6 of the Marathon uplift.

Fukuji Area, Gifu Prefecture

Four radiolarian assemblages are described from tuffaceous shales exposed in the Ichinotani and Oso-

budani Valleys (Furutani, 1990). Age control is based solely on comparison to other Silurian radiolarian assemblages; no independent chronostratigraphic correlation exists, although the abundance of tuffaceous material indicates a strong potential for future geochronometric calibration.

Fusulfanus osobudaniensis Assemblage.—This assemblage is defined by the presence of *F. osobudaniensis* Furutani, 1990 and is characterized by abundant *Fusulfanus*, *Rotasphaera (Secuicollacta)*, *Goodbodium*, and *Entactinosphaera*. *Fusulfanus osobudaniensis* is found both in Zone 1 and the lower part of Zone 2 of the Marathon uplift. In Zone 2, it is found in co-occurrence with *Praespongocoelia fusiforma*, n. sp., whereas in the Fukuji Area, the ranges of *F. osobudaniensis* and *Praespongocoelia* do not overlap. It is therefore presumed that the lower part of Zone 2 is either not present or was not sampled in the Fukuji Area and that the *F. osobudaniensis* assemblage is correlative only to Zone 1 in the Marathon uplift.

Praespongocoelia (Spongocoelia) parva–Praespongocoelia (Spongocoelia) kamitakarensis Assemblage.—This assemblage is characterized by the presence of *Praespongocoelia parva* Furutani, 1990 and *P. kamitakarensis* Furutani, 1990 *Rotasphaera* spp., and *Zadrappolus spinosus* Furutani, 1990. All but *P. kamitakarensis* are identified in Zone 2, the *Praespongocoelia* Zone of the Marathon uplift. This assemblage is considered equivalent to the upper part of Zone 2. The lower part of Zone 2 contains *P. fusiforma* and *F. osobudaniensis*, neither of which were reported from this zone.

Zadrappolus yoshikiensis Assemblage.—This assemblage is characterized by *Zadrappolus yoshikiensis* Furutani, 1990, *Z. tenuis* Furutani, 1990, *Futobari solidus* Furutani, 1990, and *F. morishitai* Furutani, 1990, but these taxa also are shown to occur in *Stylosphaera ? sp. A–Stylosphaera ? sp. B* assemblage. Taxa belonging to *Rotasphaera* is also reported from this assemblage. *Zadrappolus yoshikiensis* and *Z. tenuis* make their first appearance in the upper part of Zone 3 in the Marathon uplift, but are not considered diagnostic because they range through Zone 4 and into Zone 5. The *Z. yoshikiensis* assemblage may be correlative to the upper part of Marathon uplift Zone 3, yet it may also be correlative to the uppermost part of the *Rotasphaera* Superzone above Zone 4. At present, there are insufficient data to demonstrate whether the *Z. yoshikiensis* assemblage is stratigraphically below the *Stylosphaera ? sp. A–Stylosphaera ? sp. B* assemblage.

Stylosphaera ? sp. A–Stylosphaera ? sp. B Assemblage.—This assemblage is characterized by the distinct *Stylosphaera ? sp. B* Furutani, 1990 which possesses bladed to grooved robust, bipolar spines, and by the thinner-spined *Stylosphaera ? sp. A* Furutani,

1990. Species of *Zadrappolus* and *Futobari* characteristic of the *Z. yoshikiensis* assemblage are also reported. This assemblage is considered equivalent to Zone 4 of the Marathon uplift. *Stylosphaera* ? sp. B is synonymous with *S. (?) magnaspina*, n. sp., characteristic of Zone 4, and *Zadrappolus* spp. are also common in Zone 4. Rotasphaerids occur in Zone 4, yet are not reported in this assemblage. Zone 4 rotasphaerids are rare, small, and were initially overlooked in the Marathon uplift material. It is possible that they also may be present in the Fukuji area material in minute numbers. Furutani interprets this assemblage to be younger than the *Z. yoshikiensis* assemblage because the spine morphology of *Stylosphaera* ? sp. A and B resembles that of younger Middle and Late Devonian faunas, however, no stratigraphic evidence supports or refutes this interpretation. It is equally likely that this assemblage may occur below the *Z. yoshikiensis* assemblage because *Z. yoshikiensis* taxa occur both above and below *S. (?) magnaspina* in the Marathon uplift. The age of this assemblage was presumed to be Devonian, based solely on the presence of radiolarians with bladed spines, because Middle and Late Devonian radiolarian assemblages contain abundant forms with bladed spines. Correlation of this zone to Zone 4 of the Marathon uplift suggests its age is no younger than Late Silurian.

Stylosphaera ? sp. C Assemblage. — *Stylosphaera* ? sp. C Furutani, 1990 is the only species reported from this assemblage. It bears strong resemblance to *Stylosphaera* ? sp. B, and may be more or less equivalent. Both *Stylosphaera* ? sp. B and C appear to have robust grooved spines and fall within the intraspecific variation observed in *S. (?) magnaspina*, n. sp. *Fusalfanus*, *Zadrappolus*, and *Cenosphaera hexagonalis* Aberdeen, 1940 are also reported from this assemblage, indicating that it is probably close in age to the *Stylosphaera* ? sp. B assemblage.

SYSTEMATIC PALEONTOLOGY

INTRODUCTION

Radiolarian Species Concept

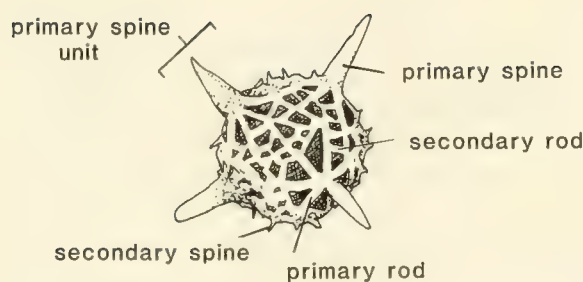
The species concept varies greatly among radiolarian specialists, the largest differences existing between paleontologists and neontologists. Living species of radiolarians reproduce sexually and their classification follows the biological species concept where genotypic variation between non-interbreeding populations is considered the fundamental criteria for distinguishing between species. Studies of living radiolarians involve the integration of reproductive biology with the study of comparative physiology, ecology, and molecular biology (e.g., Holland and Enjumet, 1960; Petrushevskaya, 1971). These studies show that the phenotypic expression of the skeleton does not necessarily reflect

genotypic distinction at the species level. Critical discussions by Shaw (1969) and Riedel (1978) of the applicability of the species concept to paleontology point out the subjectivity involved in binomial classification. By necessity, fossil taxa are classified entirely on the basis of skeletal morphology, thereby making their relationship to biologic species at best speculative.

The term morphospecies has been used by some (e.g., Pessagno *et al.*, 1984; Blome, 1984) to serve as a reminder that identifying fossil groups on the basis of skeletal morphology is distinct from considering them as species in a biologic sense. Morphospecies are, in essence, a collection of shapes which are interpreted to have some other relationship such as a phylogenetic, biostratigraphic, or ecologic relationship. The relationship reflected in the taxonomic scheme is generally the one of greatest interest or importance to its author. For example, a classification scheme designed for biostratigraphic utility might be considered artificial from a phylogenetic standpoint. It may not be the most appropriate manner of classification to show phylogenetic relationships and should not be expected to.

In the case of Paleozoic radiolarians, little is known about their phylogenetic relationships or ecologic constraints. Biostratigraphically, Paleozoic radiolarians are shown to be extremely useful. Consequently, the principal goal in erecting this taxonomic framework is to describe a number of characteristic radiolarian morphospecies shown to have biostratigraphic utility. The characters that distinguish taxa, however, follow Riedel's philosophy of being characters purported to have phylogenetic significance, and may help in establishing phylogenetic relationships. The following criteria have been used as a general guideline for subdividing taxa at the various hierarchical levels: Family level: internal structure, such as the presence of a medullary shell or an internal spicule; Genus level: mode of cortical and medullary wall construction, spine distribution; Species level: degree of sphericity, development of pore network, pore shape, spine shape, spine size, and number of spines. These criteria are consistent with those used by other Paleozoic workers (Nazarov, 1988; Cheng, 1986; Furutani, 1990) who interpret them to reflect phylogenetic relationships better than a classification based solely on shell symmetry and geometry.

The morphologic characters used to identify radiolarian morphospecies herein are those that are easily identifiable, insuring that the taxonomic scheme can be used by others. The criteria chosen are those that are easily recognizable using standard micropaleontological techniques of reflected light and scanning electron microscopy. All taxa described are common (greater than 5% of the specimens in at least 1 sample). Distinct taxa that are not found in sufficient abundance (less than 5 specimens) to study adequately are figured



Text-figure 8.—Schematic diagram showing skeletal elements of the Rotasphaeridae.

but not formally described. Characteristics that are difficult to recognize (e.g., internal skeletal characteristics), or are fragile and not always preserved, are avoided so taxa can be consistently identified. Differential preservation can alter the appearance of specimens by removing certain features, such as delicate spines. A wider latitude of variation in secondary spines is allowed in many of the morphospecies than might normally be considered when working with material which is consistently well-preserved.

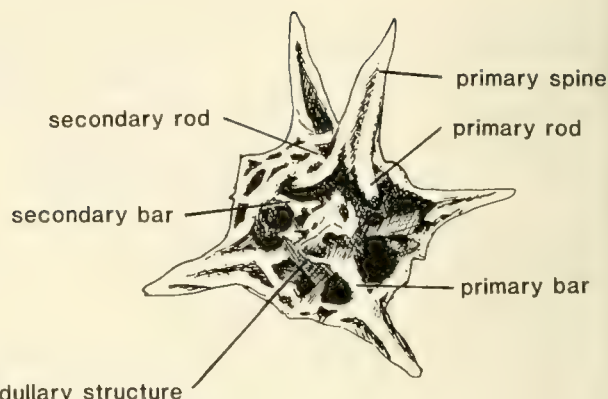
All holotypes are assigned U.S. National Museum specimen numbers (labeled USNM), and will be stored there for reference. Paratypes will be stored at the Texas Memorial Museum at the University of Texas at Austin (labeled TMM). A formal diagnosis appears for all new taxa and for all amended taxa. An informal description is provided for previously described taxa.

Morphological Terminology

A number of new groups of radiolarians are introduced herein and require the erection of new terminology to describe them. The terminology describing Rotasphaeracea n. superfam. follows that introduced by Holdsworth (1977) to describe the 'rotasphaerids,' and that used by Furutani (1990) to describe species of *Secuicollacta* Nazarov and Ormiston, 1984. The skeletal elements for Rotasphaeracea are illustrated in Text-figures 8 and 9. The following new terms are introduced:

1. "Primary spine unit" refers to a single primary spine and the primary rods emanating from its base in a spoke-like fashion (Text-figure 8). Furutani (1990, p. 49) refers to this feature as a "spine unit consisting of a main spine and some bars radiating from the base of the spine."

2. "Primary rod" refers to the rods emanating from the base of the primary spines (Text-Figures 8, 9) and is equivalent to the feature Furutani (1990, p. 49) refers to as a "bar." Furutani's use of the term "bar" is not adopted herein because the term "primary bar" has a separate meaning in spumellarian terminology and refers to the extension of the primary spine inside of the cortical shell.



Text-figure 9.—Schematic diagram showing skeletal elements of the Pseudorotasphaeridae.

3. "Secondary rod" (Text-figures 8, 9) refers to the shorter rods that are not part of the primary spine unit but instead connect the primary rods together to help form the cortical meshwork.

4. "Tenting" is defined as the degree that the primary rods deviate from a plane perpendicular to the primary spine. When the primary rods diverging from the primary spine all lie in a plane, the spine base is not considered tented. If the primary rods diverge out of the plane in a conical fashion, much like the legs of a tripod, the spine base is considered to be tented.

The following new terms are introduced to describe features observed in *Pseudospongoprimum* Wakamatsu *et al.* and in Palaeoactinosphaeridae n. fam.:

1. "Collar pores" refer to the pores that encircle a primary spine on the cortical shell.

2. "Collar grooves" refer to grooves that run longitudinally up a primary spine, starting from a collar pore at the base.

RELATIONSHIP BETWEEN THE ROTASPHAERIDAE AND PSEUDOROTASPHAERIDAE

This paper introduces several widely distributed yet previously undescribed families of Spumellariina. Two of the more important groups considered are the Rotasphaeridae and the Pseudorotasphaeridae. These two families share a distinct cortical shell morphology, the rotasphaerid structure (Text-figure 8), and are considered to be one of the more characteristic components of Late Ordovician and Silurian radiolarian assemblages. All Spumellariina that exhibit the rotasphaerid structure are grouped into the superfamily Rotasphaeracea. The first Rotasphaeracea described (Holdsworth, 1977) lack any type of internal structure, which has lead me to interpret the mode of shell construction as arising from the coalescence of rays emerging from multiple primary spine centers (Text-figure 8). Rotasphaeracea lacking internal structures are classified in the family Rotasphaeridae. It has become apparent

through the examination of some broken specimens, however, that some forms exhibiting the rotasphaerid structure also have an internal structure. From the outside, some of these forms easily pass for rotasphaerids. In addition to the rotasphaerid structure, the number and placement of spines, development of the cortical meshwork, and development of secondary spines all are similar to that of the rotasphaerids. All taxa with an internal structure and the rotasphaerid structure on the cortical shell are placed into the family Pseudorotasphaeridae.

Preservational problems prevent the nature of the Pseudorotasphaeridae internal structure from being fully described at this time. In those specimens in which the structure can be seen, it appears to vary from a doubled shell to a loose inner framework connected to the cortical shell by thin bars that join at the base of the primary spines and at other points on the cortical shell (Text-figure 9). A broken specimen showing the internal structure was examined with scanning electron microscopy (Pl. 4, figs. 1, 2) and revealed that primary bars connecting the internal structure to the primary spine appear to be hollow tubes, whereas the secondary bars connecting to the cortical shell appear to be thinner solid rods. Future study of material with better preserved internal structures may further clarify the relationship between the Pseudorotasphaeridae and the Rotasphaeridae.

Class **ACTINOPODA** Calkins, 1909

Subclass **RADIOLARIA** Müller, 1858

Order **POLYCYSTIDA** Ehrenberg, 1838

Suborder **SPUMELLARIINA** Ehrenberg, 1838

ROTASPHAERACEA, new superfamily

Diagnosis.—Test composed of a single cortical shell or one cortical and one medullary shell. Cortical shell possesses a rotasphaerid structure, consisting of four or more rods emanating from the base of each primary spine in a spoke-like fashion. Rods from different spine centers coalesce to form the principal meshwork of the cortical shell.

Remarks.—This superfamily is composed of two families, the Rotasphaeridae and the Pseudorotasphaeridae, both of which possess the rotasphaerid structure on the cortical shell, but differ fundamentally in that the Rotasphaeridae lack a medullary shell. The pseudorotasphaerids possess an irregularly shaped medullary shell and commonly have a thicker cortical shell, due to the advanced development of secondary spines (Pl. 4, figs. 3, 4). Many of the Pseudorotasphaeridae bear strong resemblance to the Rotasphaeridae, with exception of the internal structure. Based on this strong external resemblance, they are linked at the superfamily level.

Range and occurrence.—Late Ordovician through Late Silurian, reported from west Texas, the Canadian Archipelago, Kazakhstan, and Japan.

ROTASPHAERIDAE, new family

Type genus.—*Rotasphaera*, new genus

Diagnosis.—Test composed of a single cortical shell formed by the coalescence of six or more primary spine units. Each unit consists of a primary spine more or less perpendicular to five or more straight rods (commonly six) which radiate from its base in a spoke-like fashion. The rods coalesce from the individual spine units to form a coarse latticed network of large polygonal pore frames. Pore framework is further subdivided by the development of secondary rods that connect the primary rods together (Text-figure 8).

Remarks.—This group was first described by Holdsworth (1977) as the informal group "Rotasphaerids." The distinct radiating structure of the primary spine units is what Holdsworth referred to as the rotasphaerid structure. Included in the Rotasphaeridae is *Rotasphaera* n. gen. and the genus *Secuicollacta* Nazarov and Ormiston, 1984 emended herein. These two genera differ in the number of primary spines and the degree of development of secondary spines. *Secuicollacta* Nazarov and Ormiston (1984) was originally classified under the Haplentactiniidae Nazarov (1980) because it was interpreted to have an internal spicule and weakly developed cortical shell; two characteristics diagnostic of the Haplentactiniidae. After examining photographs of the type species, *Secuicollacta cassa*, I interpret the feature referred to as an ectopically placed spicule to be a rotasphaerid structure, and one of several primary spine units. *Secuicollacta cassa* is therefore, formally reclassified under Rotasphaeridae.

Range and occurrence.—Members of the family Rotasphaeridae are interpreted to be the most primitive of the Rotasphaeracea. The oldest reported occurrence is from the Late Ordovician (Renz, 1990). These Rotasphaeridae possess a single, loosely latticed cortical shell with six or more rod-shaped primary spines and poor secondary bar development. The youngest reported occurrence of Rotasphaeridae comes from the Late Silurian of the Marathon uplift, west Texas.

Genus ROTASPHAERA, new genus

Type species.—*Rotasphaera marathonensis*, new species

Diagnosis.—Shell may be round to polygonal in outline with six to nine primary spines which are morphologically distinct from the secondary spines. Primary spines are commonly blunt-ended or tapered, may exhibit blades or grooves at the proximal end, and are circular in cross section at the distal end. Secondary

Table 2.—Measurements (in μm) of *Rotasphaera beckwithensis*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	106	84	140	(11)
avg. length primary spine	55	37	65	(11)
avg. length secondary spine	6	5	9	(7)
width primary spine base	20	16	26	(11)
width secondary spine base	3.5	3	4	(5)
diameter primary spine unit	51	37	65	(11)

spines are commonly thin nontapered rods or nodes which range from 5 to 50% of the primary spine length.

Remarks.—*Rotasphaera* is distinguished from *Seuicollacta* Nazarov and Ormiston, 1984, emended herein, by having fewer primary spines and more differentiation between primary and secondary spine morphology. Many *Rotasphaera* have seven primary spines which give the shell a hexacubic appearance. Specimens can commonly be oriented so that two of these spines are positioned at opposite poles, and the remaining five occur equatorially. Pore development is also variable. *Hexastylus basiporosus* (Aberdeen, 1940, p. 136, pl. 21, figs. 6, 9, 13) appears to belong to the genus *Rotasphaera*, yet its identification at the species level is not possible in thin-section and it is treated as *nomen dubium*.

Taxa within *Rotasphaera* are distinguished from each other by variations in the following characteristics:

1. Degree of sphericity and tenting. Non-tented taxa tend to have a spherical outline, like *Rotasphaera marathonsensis*, n. sp., whereas tented taxa have a polygonal outline, such as *Rotasphaera beckwithensis*, n. sp.

2. Number, shape, and size of primary spines.

3. Diameter of primary spine units relative to shell diameter.

4. Degree of secondary rod development. Secondary rod development is directly reflected in the development of the cortical shell pore network. Taxa with poorly developed secondary rods have angular pores of varying shape and size, such as *Rotasphaera nuda*, n. sp., whereas those with more extensive secondary rod development have a more regularly shaped pore network and often smaller pores, such as with *Rotasphaera robertsoni*, n. sp.

5. Shape and size of secondary spines and their degree of development. Secondary spines vary from small nodes to thin rods, yet in all cases secondary spines are substantially smaller and thinner than primary spines. Preservation of delicate secondary spines may be in part preservationally controlled. Therefore, less emphasis is placed on secondary spine development than on other features.

***Rotasphaera beckwithensis*, new species**
Plate 2, figures 7–12; Plate 8, figure 4, 5

Diagnosis.—Test subcircular with six to seven primary spines. Primary spines are robust and tapered and measure approximately 50% the cortical shell diameter. Six to seven wedge-shaped grooves and alternating ridges at base and extend up 15 to 30% of the spine length. Six primary rods extend from spine bases with minor tenting. Diameter of primary spine units are 45% of shell diameter. Secondary rod development is moderate resulting in very angular pores. Secondary spines are thin rods, three to four microns in width, and 25% the length of the primary spine.

Comparison.—*Rotasphaera beckwithensis* can be distinguished from *Pseudorotasphaera communis*, n. sp. by its fewer, more robust primary spines, and from *R. marathonsensis*, n. sp. by its subcircular outline and shorter, more tapered primary rods. Secondary spines are thin and delicate and are commonly not preserved, leaving a nodose appearance to the cortical shell.

Measurements.—See Table 2.

Type locality.—East Bourland Mountain, Marathon uplift, west Texas.

Etymology.—Named for the Beckwith Hills, near the type locality.

Designation of types.—Holotype USNM 466291, paratype TMM 1850TX2.

Range and occurrence.—Silurian, Zones 2 and 3 of the Marathon uplift, west Texas.

***Rotasphaera delicata*, new species**
Plate 2, figures 17, 18

Diagnosis.—Subcircular shell with six to seven long, slender primary spines. Primary spines are cylindrical and are approximately 70% the length of the cortical shell diameter. Five to six thin primary rods extend from primary spine base with minor tenting. Diameter of primary spine unit is small, comprising about 35% of shell diameter. Thin, poorly developed secondary rods create a delicate open meshwork of irregularly shaped pores. Secondary spines occur as nodes and commonly are not preserved.

Remarks.—This species is distinguished by its delicate open meshwork and long slender spines.

Measurements.—See Table 3.

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—(L.) *delicatus* = delicate.

Designation of types.—Holotype USNM 466292, paratype TMM 1849TX3.

Range and occurrence.—Silurian, Zone 1 through lower Zone 3 of the Marathon uplift, west Texas.

Table 3.—Measurements (in μm) of *Rotasphaera delicata*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	104	88	121	(6)
avg. length primary spine	70	65	81	(6)
avg. length secondary spine	7	5	8	(3)
width primary spine base	17	15	19	(6)
diameter primary spine unit	40	37	47	(6)

***Rotasphaera marathonensis*, new species**

Plate 2, figures 1–4; Plate 8, figures 1, 2

Rotasphaerid morphotype A Noble, 1993b, p. 278, pl. 1, fig. 1.

Diagnosis.—Test with circular outline possessing six to seven primary spines. Primary spines are cylindrical, tapering towards the distal third, are blunt-ended, and usually measure slightly more than 50% of the shell diameter. Spine base is composed of five to seven rods with little to no tenting. Primary spine unit diameter measures approximately 35% of shell diameter. Secondary rod development is moderate and pores are moderately large. Secondary spines are well developed thin rods that are approximately 30 to 40% the length and width of the primary spines.

Remarks.—Presence of secondary spines appears to be controlled partly by preservation. Paratypes include forms where spines have broken off, resulting in an altered appearance from the holotype.

Comparison.—*Rotasphaera marathonensis* differs from *Rotasphaera robertsorum* by having larger pore frames, and from *Rotasphaera beckwithensis* by having a more circular outline with non-tented primary spine units.

Measurements.—See Table 4.

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—This commonly occurring rotasphaerid is named for the Marathon uplift.

Designation of types.—Holotype USNM 466290, paratype TMM 1849TX2.

Range and occurrence.—Silurian, Zones 2 through 4, Marathon uplift, west Texas.

***Rotasphaera nuda*, new species**

Plate 1, figures 17, 18

Diagnosis.—Small, subcircular shell with six to seven cylindrical, slightly tapered primary spines approximately 50% the cortical shell diameter. Six to seven faint, shallow grooves are sometimes seen at base of primary spines. Commonly six primary rods with minor tenting extend from each spine base to form coarse angular meshwork with poor secondary rod development. Secondary spines are not developed.

Table 4.—Measurements (in μm) of *Rotasphaera marathonensis*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	127	112	154	(9)
avg. length primary spine	58	49	65	(9)
avg. length secondary spine	17	13	19	(9)
width primary spine base	19	18	20	(9)
width secondary spine base	6	5	7	(7)
diameter primary spine unit	45	37	51	(9)

Remarks.—Absence of secondary spines may be a function of poor preservation. In species where secondary spines are poorly preserved, such as *Rotasphaera delicata*, they leave nodes or remnants at the point where the secondary spine joins the cortical shell. Very minor nodes are seen at some pore junctures in *Rotasphaera nuda*. These nodes may indicate very delicate secondary spines that were not preserved, but is presently speculative.

Comparison.—*Rotasphaera nuda* is similar to *Rotasphaera quadrata* n. sp. but is distinguished by having a more open pore network with poorly developed secondary rods, and having a less quadrate outline. It differs from *Rotasphaera delicata* n. sp. by having more robust, shorter primary spines, and a less rounded outline.

Measurements.—See Table 5.

Type locality.—East Bourland Mountain, Marathon uplift, west Texas.

Etymology.—(L.) *nudus* = bare.

Designation of types.—Holotype USNM 466293, paratype TMM 1850TX3.

Range and occurrence.—Silurian, Zones 1 through 3 of the Marathon uplift, west Texas.

***Rotasphaera quadrata*, new species**

Plate 2, figures 13–16, 19, 20

Diagnosis.—Test quadrate in outline with six to eight long, cylindrical to slightly tapered primary spines. Primary spines are 60 to 80% as long as the shell diameter. Six of the spines occur orthogonally with additional spines added asymmetrically. Six to seven primary rods extend from each primary spine base and are highly tented, contributing to the shell's quadrate outline.

Table 5.—Measurements (in μm) of *Rotasphaera nuda*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	108	93	130	(7)
avg. length primary spine	53	47	65	(7)
width primary spine base	15	14	17	(7)
diameter primary spine unit	52	42	56	(7)

Table 6.—Measurements (in μm) of *Rotasphaera quadrata*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	86	74	112	(8)
avg. length primary spine	58	56	70	(8)
avg. length secondary spine	9	5	18	(3)
width primary spine base	19	14	20	(8)
width secondary spine base	3	2	4	(5)
diameter primary spine unit	47	37	56	(8)

Tenting in spine bases forms 6 to seven wedge-shaped grooves alternating with the primary rods at base of spine. Grooves may extend as much as 50% of the primary spine length. Secondary rod development is moderate, resulting in polygonal pore frames. Secondary spines are short thin rods approximately 20% the length of the primary spines and commonly are not preserved.

Comparison.—This species is distinguished from other species of *Rotasphaera* by its quadrate shell, high degree of tenting, and long straight spines. It is distinguished from *R. delicata* by having thicker pore frames and a more quadrate outline.

Measurements.—See Table 6.

Type locality.—East Bourland Mountain, Marathon uplift, west Texas.

Etymology.—(L.), *quadratus* = square.

Designation of types.—Holotype USNM 466294, paratypes TMM 1844TX2, TMM 1857TX1.

Range and occurrence.—Late Silurian, Zone 3 of the Marathon uplift, west Texas.

***Rotasphaera robertsororum*, new species**

Plate 2, figures 5, 6

Rotasphaerid morphotype A Noble, 1993b, p. 278, pl. 1, fig. 4.

Diagnosis.—Test circular in outline possessing six to seven blunt-ended primary spines measuring approximately 50% of the shell diameter. Seven to eight primary rods extend from spine bases and are non-tented. Diameter of primary spine units are approximately 30% of shell diameter. Secondary rods are well developed. Secondary spines are thin and rod-shaped and commonly are not preserved.

Remarks.—Well-developed secondary rods in *R. robertsororum* producing polygonal pore frames that are small and more regularly shaped, relative to of the species of *Rotasphaera*.

Comparison.—*R. robertsororum* differs from *R. marathonsensis*, n. sp. by having more primary rods per primary spine, better developed secondary rod structure, and smaller pores.

Measurements.—See Table 7.

Table 7.—Measurements (in μm) of *Rotasphaera robertsororum*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	110	84	140	(6)
avg. length primary spine	52	53	74	(6)
avg. length secondary spine	7	5	9	(6)
width primary spine base	15	11	19	(6)
width secondary spine base	3	2	4	(6)
diameter primary spine unit	34	28	37	(6)

Type locality.—East Bourland Mountain, Marathon uplift, west Texas.

Etymology.—This species is named in honor of the Roberts family of Marathon Basin for their valuable assistance in geologic investigations in the Marathon uplift for over 50 years.

Designation of types.—Holotype USNM 466295, paratype TMM 1850TX4.

Range and occurrence.—Silurian, Zones 2 and 3 of the Marathon uplift, west Texas.

Genus SECUCOLLECTA Nazarov and Ormiston, 1984

Type species.—*Secuicollecta cassa* Nazarov and Ormiston, 1984

Emended diagnosis.—*Rotasphaerid* composed of a single cortical shell with nine or more, commonly 12, primary spines, slight tenting. Secondary spines may be poorly or moderately developed.

Remarks.—Nazarov and Ormiston (1984) state that *Secuicollecta* should be classified with “*Rotasphaerids*” of Holdsworth (1977), yet their diagnosis differs substantially from the description of Holdsworth’s “*Rotasphaerids*.” Instead, Nazarov and Ormiston (1984) describe *Secuicollecta* as possessing an ectopically placed spicule consisting of five to seven straight rays with one perpendicular rod-like spine. Secondary development of lattice-work enveloping this spicule is interpreted by these authors as the mode of shell development. Furutani (1990) describes several new species of *Secuicollecta*, notes that his taxa possess multiple primary spine units, and thus believes his taxa confer more with the definition of “*Rotasphaerids*” than with the definition of *Secuicollecta*. Furutani was uncertain if the type species, *Secuicollecta cassa*, possessed a single spine unit or multiple primary spine units, however, and made no formal emendation of the diagnosis to match that of the “*Rotasphaerids*.” I agree with Nazarov and Ormiston (1984) and Furutani (1990) that *Secuicollecta* and Holdsworth’s “*Rotasphaerids*” are the same. Photos of *Secuicollecta cassa* are oriented so that one primary spine unit shows prominently (Nazarov and Ormiston 1984, pl. IV, fig.

5; Nazarov 1988, pl. XII, fig. 2; Nazarov and Ormiston, in press, pl. 4, fig. 3). Other large spines are visible and they appear to have primary rods emanating from them in a rotasphaerid fashion. I agree with Furutani that the ectopically placed spicule of *Secuicollacta* is one of a number of primary spine units. Therefore, *Secuicollacta* should be classified with the Rotasphaeridae, not the Haplentactiniidae.

Although the type species, *Secuicollacta cassa*, is a rotasphaerid, the species *Secuicollacta amoenitas* (Nazarov, 1988, pl. XVI, fig. 2) is not a rotasphaerid and does not belong in the same genus with *Secuicollacta cassa*. *Secuicollacta amoenitas* appears to have an internal structure that fits the original generic description of *Secuicollacta*, with an ectopically placed internal spicule. It is described from the *Tetrentactinia barysphaera*—*Ceratoikiscum famenium* Zone of Late Famennian (latest Devonian age) and clearly has no relationship to the rotasphaerids which make their last appearance in the Late Silurian, 40 Ma earlier. The presence of an eccentric an internal spicule in *Secuicollacta amoenitas* would justify its classification in the Haplentactiniidae Nazarov, 1980. I am not able to make a formal taxonomic revision of *Secuicollacta amoenitas* in this paper, however, because I have not examined the actual specimens and cannot adequately describe it from the photographs. Since there is no genus that *S. amoenitas* fits into, a new genus will need to be erected by someone who has access to material that contains *S. amoenitas*.

Taxa within *Secuicollacta* are distinguished from each other by variations in:

1. Number and shape of primary spines. Primary spines may be rod-shaped, like *Secuicollacta cassa*?, distally tapered, like *Secuicollacta solara*, or flattened, like *Secuicollacta* (?) *platyspina*.

2. Development of secondary spines and their degree of morphological divergence from primary spine morphology.

Range and occurrence.—Silurian, Zones 1 through 4 of the Marathon uplift, west Texas, Kurosegawa Tectonic Zone and Fukuji Area, Japan, southern Urals, Kazakhstan.

***Secuicollacta cassa*, Nazarov and Ormiston**

?*Palaeohippium* ? cf. *echinatum* Nazarov, B.B. 1988, p. 209, pl. XII, fig. 5.

Emended diagnosis.—Test round in outline with a minimum of ten long, thin, rod-shaped primary spines. Six primary rods emerge from spine bases with minor tenting. Secondary rod development is poor and meshwork is coarse with large irregularly shaped pores. Secondary spines are weakly developed, short, thin rods.

Remarks.—The original diagnosis of *Secuicollacta cassa* describes an ectopically placed spicule consisting

Table 8.—Measurements (in μm) of *Secuicollacta cassa*?. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	141	130	158	(6)
avg. length primary spine	58	47	74	(6)
width primary spine base	17	14	19	(6)

of five to seven straight rays with one perpendicular rod-like spine. As was discussed in the remarks section under the genus, the feature described as an ectopically placed spicule is interpreted to be one of a number of rotasphaerid primary spine units that was mistaken for an ectopic spicule. Therefore, the emended diagnosis differs substantially from the original but is believed to more accurately describe the actual morphology. A specimen identified as *Palaeohippium* ? cf. *echinatum* (Nazarov, B.B. 1988, p. 209, pl. XII, fig. 5) is a rotasphaerid that may also be conspecific with *S. cassa*, but the spines are not sufficiently well preserved to be certain.

Comparison.—*Secuicollacta cassa* differs from other species of *Secuicollacta* by its rod-shaped primary spines, and its sparse, thin secondary spines.

***Secuicollacta cassa* ?, Nazarov and Ormiston, 1984 Plate 1, figures 1, 2**

Diagnosis.—Test round in outline with a minimum of 12 long, thin, rod-shaped primary spines. Six primary rods emerge from spine bases with minor tenting. Secondary rod development is poor and meshwork is coarse with large irregularly shaped pores. Secondary spines are sparse nodes.

Remarks.—Specimens of *Secuicollacta cassa* ? recovered from the Caballos Novaculite differ slightly from the type specimen of *S. cassa* by having more poorly developed secondary spines. Unfortunately, only one specimen of *S. cassa* has been published and it is difficult to determine the latitude of intraspecific variation recognized by the original authors. The lack of secondary spines in the Caballos material is very likely a function of preservation. *Secuicollacta cassa* ? may be distinguished from other species of *Secuicollacta* and *Rotasphaera* by its simple, thin, rod-shaped spines, and poor secondary spine development.

Measurements.—See Table 8.

Range and occurrence.—Silurian, Zones 1 through 3 of the Marathon uplift, west Texas.

***Secuicollacta foliaspinella*, new species Plate 1, figures 9–12**

Rotasphaerid morphotype B Noble, 1993b, p. 278, pl. 1, fig. 2.

Diagnosis.—Shell circular in outline with 10 or more thin, slightly tapered, blunt-ended primary spines,

Table 9.—Measurements (in μm) of *Secuicollacta foliaspinella*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	143	121	158	(7)
avg. length primary spine	53	47	65	(6)
avg. length secondary spine	35	28	37	(5)
width primary spine base	19	18	20	(7)
width secondary spine base	12	9	17	(7)

commonly with six primary rods. Primary spines are short, measuring between 30 to 40% of shell diameter, and are not substantially larger than the secondary spines. Spine bases are non-tented. Secondary rod development is moderate and pores are rounded but irregularly shaped. Pore size is highly variable. Some secondary spines are connected in a flange-like fashion. Secondary spines are well developed, blades approximately 60% the length and width of the primary spines.

Comparison.—*Secuicollacta foliaspinella* is similar to *S. itoigawai* Furutani, 1990 in that they are both large with well developed primary and secondary spines, and that they are circular to subcircular in outline. They differ in that *S. foliaspinella* has distinct flanges connecting primary and secondary spines, and primary spines are shorter, blunt-ended and slightly tapered. Primary spines on *S. itoigawai* are longer, non-tapered, and morphologically more similar to *S. cassa*.

Measurements.—See Table 9.

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—(L.) *folium* = leaf, *spinellus* = little spine.

Designation of types.—Holotype USNM 466286, paratypes TMM 1850TX1, TMM 1854TX1.

Range and occurrence.—Silurian, Zones 2 and 3 of the Marathon uplift, west Texas.

Secuicollacta (?) *platyspina*, new species

Plate 1, figure 16

Diagnosis.—Large shell with spiked appearance due to 12 or more bladed knife-like primary spines. Six to seven thick primary rods radiate from each spine base and form several bladed ridges. Secondary spines of

Table 10.—Measurements (in μm) of *Secuicollacta* (?) *platyspina*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	143	130	158	(5)
avg. length primary spine	63	56	67	(5)
avg. length secondary spine	54	47	60	(5)
width primary spine base	28	24	35	(5)
width secondary spine base	21	19	26	(5)

Table 11.—Measurements (in μm) of *Secuicollacta solara*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	127	112	140	(8)
avg. length primary spine	63	51	74	(8)
avg. length secondary spine	41	28	56	(8)
width primary spine base	20	18	23	(8)
width secondary spine base	13	9	17	(8)

similar appearance, yet are smaller (80 to 90% of primary spine length). Bladed secondary spines obscure the pore network, yet pores seem to be angular. Pore diameter is approximately equal to pore frame thickness.

Comparison.—*Secuicollacta* (?) *platyspina* bears resemblance to and is most likely a descendant of *S. solara*, n. sp. It differs from *Secuicollacta solara* in that all spines are flattened blades, whereas the spines of *S. solara* are blunt-ended, slightly tapered rods.

Measurements.—See Table 10.

Type locality.—East Bourland Mountain, Marathon uplift, west Texas.

Etymology.—(Gr.) *platys* = flat, (L.) *spina* = spine.

Designation of types.—Holotype USNM 466287, paratype TMM 1844TX1.

Range and occurrence.—Late Silurian, Zone 3 of the Marathon uplift, west Texas.

Secuicollacta solara, new species

Plate 1, figures 3–8; Plate 8, figures 3, 6

Secuicollacta sp. cf. *S. horrida* Furutani, 1990, p. 51, pl. 11, figs. 6, 7.

Description.—Test polygonal in outline with 10 to 15 tapered primary spines. Six to seven primary rods with moderate tenting radiate from spine bases. Meshwork is open and pores are large, irregularly shaped polygons. Secondary spines are well developed and vary in size from 30 to 50% of primary spine size.

Remarks.—Some of the larger secondary spines have the appearance of a small primary spine with four primary rods. It is believed that these are secondary spines emerging at a four-way juncture, yet they may possibly be earlier growth stages of primary spines.

Comparison.—*Secuicollacta solara* is distinguished from *Secuicollacta horrida* by having slightly thicker, shorter, and more tapered primary spines, and by having more numerous secondary spines.

Measurements.—See Table 11.

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—(L.) *solaris* = sun.

Designation of types.—Holotype USNM 466289, paratype TMM 1849TX1.

Range and occurrence.—Silurian, Zones 1 through 3 of the Marathon uplift, west Texas, *Fusalfanus osobudaniensis* Zone of Fukuji Area, Gifu Prefecture, Japan.

***Secuicollacta* sp. A**

Plate 1, figure 15

Diagnosis.—Shell polygonal in outline with 10 or more primary spines. Six thick primary rods extend from each spine base with moderate tenting. Secondary rod formation is poor and pore network is coarse and highly angular. Secondary spines are sparse and stubby.

Remarks.—This species exhibits prominent primary rods which appear to have overlapping relief with intersecting rods, much like the relief between overlapping strands of a ball of twine.

Comparison.—It can be distinguished from *S. solara* by its prominent primary rods and by its highly angular pores. This species is not formally described because of lack of an adequate number specimens.

Range and occurrence.—Silurian, Zone 1 of the Marathon uplift, west Texas.

Family PSEUDOROTASPHAERIDAE, new family

Type genus.—*Pseudorotasphaera*, new genus

Diagnosis.—Cortical shell of angular meshwork connected to loosely latticed medullary shell. Six to seven robust and commonly grooved primary spines. Five to six rods radiate from the base of each primary spine, as in the Rotasphaeridae, and diffuse into the pore network. The medullary shell is attached to the cortical shell by primary bars extending from the primary spines and by secondary bars extending from other points on the shell cortical shell (Pl. 4, figs. 1 and 2). Spines are heavily grooved at the proximal end and spine bases are tented, commonly giving shells a polygonal outline. Cortical shell may develop secondary spines giving it a three-dimensional, thickened appearance.

Remarks.—The Pseudorotasphaeridae have an external appearance which is similar to the Rotasphaeridae. Primary spines have a rotasphaerid structure with five or six rods emanating from each primary spine base and serving as the framework for the cortical shell. In some cases, resemblance to the Rotasphaeridae is so strong that a positive distinction can only be made by inspection of the internal structure. The thickened, dense cortical shell of many Pseudorotasphaeridae make internal inspection difficult. The internal structures were observed in broken specimens (Pl. 8, figs. 10 and 11) and unbroken specimens with relatively thin cortical shells, like *Pseudorotasphaera communis* (Pl. 8, figs. 8, 9, and 12). It is presently unclear whether the rotasphaerid structure is formed in the same manner in both the true Rotasphaeridae and the Pseudorotasphaeridae.

Comparison.—In addition to having a medullary shell, the Pseudorotasphaeridae differ from the Rotasphaeridae by having primary spines that are more heavily grooved, and more diffuse primary rods.

Range and Occurrence.—Silurian, restricted to the Rotasphaerid Superzone, in the Marathon uplift, west Texas. *Pseudorotasphaera* may also occur in Japan. An undescribed specimen from the Fukuji area called *Secuicollacta* sp. B (Furutani, 1990, pl. 13, fig. 8) has robust, grooved spines and may be a pseudorotasphaerid.

Genus PSEUDOROTASPHAERA, new genus

Type species.—*Pseudorotasphaera hispida* Noble, new species

Diagnosis.—Latticed cortical shell polygonal to subcircular in outline with six to seven robust, grooved primary spines. Pore frames are angular to subcircular. Each spine base possesses five to six rods which are continuous with the spine ridges. A loosely latticed medullary shell attaches to the cortical shell by primary bars which extend to each primary spine, and by thin secondary bars connecting to other points on the cortical shell.

Remarks.—Species of *Pseudorotasphaera* may be distinguished by differences in cortical shell sphericity, the shape, length and thickness of the primary spines, size of spine base relative to size of the cortical shell, and the shape, thickness, and abundance of secondary spines. Some species appear with a query (?) because although they possess the external characteristics of *Pseudorotasphaera*, the internal structure could not be verified.

Range and occurrence.—Silurian, Rotasphaerid Superzone of the Marathon uplift, west Texas and possibly Japan (see range and occurrence of family).

***Pseudorotasphaera hispida*, new species**

Plate 3, figures 5–7; Plate 4, figures 3, 4

Diagnosis.—Test subcircular in outline with six to seven primary spines. Cortical shell is thickened so that pore-frames are ridge-like and sub-angular (Pl. 4, figs. 3, 4). Primary spines are extremely robust and tapered. Five to six prominent wedge-shaped grooves and alternating ridges run the entire length of the spine. Width of grooves at spine base is commonly one and a half to two times as wide as ridges. Primary spine units encompass approximately 60% of the cortical shell diameter. Pores are subangular, ranging from 6 to 10 microns in diameter. Cortical surface is covered with thin, short secondary spines which may bifurcate at their termination. Primary bars extend inward from the cortical shell to join an open meshed inner shell.

Remarks.—Specimens may vary in their appearance, based on the degree of secondary spine preser-

Table 12.—Measurements (in μm) of *Pseudorotasphaera hispida*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	105	93	140	(9)
avg. length primary spine	73	56	88	(9)
avg. length secondary spine	20	15	30	(8)
width primary spine base	33	28	42	(7)
diameter primary spine unit	61	56	65	(9)

vation. Subcircular outline is more apparent in specimens with poorly preserved secondary spines (Pl. 3, fig. 7).

Comparison.—*Pseudorotasphaera hispida* may be distinguished from *P. lanceolata*, n. sp. by having shorter primary spines, smaller pores, and from *P. (?) robustispina*, n. sp. by having a less circular outline.

Measurements.—See Table 12.

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—(L.) *hispidus* = hairy, bristly, rough.

Designation of types.—Holotype USNM 466296, paratype TMM 1854TX2.

Range and occurrence.—Silurian, Zones 1 and 2 of the Marathon uplift, west Texas.

***Pseudorotasphaera communa*, new species**

Plate 3, figures 13–18; Plate 8, figures 8, 9, 12

Diagnosis.—Test polygonal in outline with seven primary spines. Spines have five to six grooves and alternating ridges at base which extend 50 to 80% the length of the spine. Ridges which extend into five to six primary rods at base of primary spine diffuse into pore network. Pores are rounded to subangular in outline, ranging from five to eight microns in diameter. Secondary spines are short nodes. Medullary shell is a coarse, angular latticed polygon, connected to the cortical shell by thin primary and secondary bars (Pl. 8, figs. 8, 9, 12).

Comparison.—*Pseudorotasphaera communa* has an external resemblance to *Rotasphaera quadrata*, n. sp., but may be distinguished by having primary spines

Table 13.—Measurements (in μm) of *Pseudorotasphaera communa*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	104	88	140	(15)
avg. length primary spine	76	62	87	(15)
avg. length secondary spine	8	5	17	(6)
width primary spine base	31	26	42	(15)
diameter primary spine unit	58	47	65	(15)

Table 14.—Measurements (in μm) of *Pseudorotasphaera lanceolata*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	96	88	102	(5)
avg. length primary spine	99	84	109	(5)
width primary spine base	39	37	42	(5)
diameter primary spine unit	61	56	65	(5)

that are more strongly grooved, and by having a less quadrate outline.

Measurements.—See Table 13.

Type locality.—East Bourland Mountain, Marathon uplift, west Texas.

Etymology.—(L.) *communa* = common.

Designation of types.—Holotype USNM 466297, paratype TMM 1844TX3.

Range and occurrence.—Silurian, Zones 1 through 3 of the Marathon uplift, west Texas.

***Pseudorotasphaera lanceolata*, new species**

Plate 3, figures 8–10; Plate 8, figure 7

Diagnosis.—Test polygonal in outline with six to seven robust primary spines. Primary spines have five pronounced grooves that alternate with five bladed ridges and extend the entire length of the spine. Width of grooves at spine base is two to three times width of alternating ridges. Primary spine units cover 60% or more of cortical shell and are approximately as long as the cortical shell diameter. Pore frames are thickened and pores are large, ranging 10 to 18 microns in diameter. Only two or three pores occur in between primary spine units. Secondary spines are thin rods that are rarely preserved.

Remarks.—This species is distinguished by its long and extremely robust spines and by its large pores. The cortical area in between the spines commonly accommodates only two or three pores.

Comparison.—*Pseudorotasphaera lanceolata* is distinguished from *Pseudorotasphaera hispida*, n. sp. and *Pseudorotasphaera communa*, n. sp. by possessing longer, more robust spines, a more polygonal outline, and fewer, larger pores.

Measurements.—See Table 14.

Type locality.—Wood Hollow, Marathon uplift, west Texas.

Etymology.—(L.) *lanceolatus* = lance-shaped.

Designation of types.—Holotype USNM 466298, paratype TMM 1840TX2.

Range and occurrence.—Silurian, Zones 1 and 2 of the Marathon uplift, west Texas.

Table 15.—Measurements (in μm) of *Pseudorotasphaera* (?) *robustispina*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	114	102	130	(8)
avg. length primary spine	60	56	65	(8)
avg. length secondary spine	16	9	19	(5)
width primary spine base	28	23	33	(8)
width secondary spine base	3	3	4	(5)
diameter primary spine unit	42	35	51	(8)

***Pseudorotasphaera* (?) *robustispina*, new species**

Plate 3, figures 1–4; Plate 4, figure 5

Rotasphaerid morphotype C Noble, 1993b, p. 278, pl. 1, fig. 3.

Diagnosis.—Test circular in outline with six to seven robust primary spines. Primary spines are blunt-ended and conical with five deep wedge-shaped grooves and alternating ridges extending approximately 90% the length of the spine. Primary spine units are composed of five to six primary rods and are non-tented to slightly tented. Diameter of primary spine units makes up about 35% of shell diameter. Primary rods diffuse into pore structure and pores are subrounded, fairly regular in shape, ranging in size from five to ten microns in diameter. Thin rod-shaped secondary spines 25 to 35% the length of primary spines are present. Secondary spines are three to four microns wide and are commonly not preserved.

Remarks.—This species is tentatively placed in the *Pseudorotasphaera* because the presence of an internal medullary shell has not been confirmed. Reflected light on several specimens shows the vague outline of a polygonal body inside the cortical shell, yet this may be microcrystalline quartz infilling. Plate 4, figure 5 illustrates the common problem of chalcedony filling in the internal cavity of a specimen and illustrates the difficulties in determining the nature of internal structure.

Comparison.—This species is easily distinguished from *Rotasphaera marathonsensis*, n. sp. and *Rotasphaera robertsorum*, n. sp. by its robust grooved spines, and from *Pseudorotasphaera hispida*, n. sp. by having a rounder outline.

Measurements.—See Table 15.

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—(L.) *robustus* = robust, *spina* = spine.

Designation of types.—Holotype USNM 466299, paratype TMM 1849TX4.

Range and occurrence.—Silurian, Zone 2 of the Marathon uplift, west Texas.

Table 16.—Measurements (in μm) of *Pseudorotasphaera* (?) *rotunda*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	113	91	134	(9)
avg. length primary spine	64	54	77	(9)
avg. length secondary spine	17	14	17	(7)
width primary spine base	22	21	24	(9)
width secondary spine base	5	5	6	(7)
diameter primary spine unit	52	40	67	(9)

***Pseudorotasphaera* (?) *rotunda*, new species**

Plate 3, figures 11, 12

Diagnosis.—Test circular in outline with seven to nine robust primary spines. Primary spines are tapered with five to six shallow wedge-shaped grooves and alternating ridges at base that extend 10 to 15% along the spine length. Ridges are round and join with cortical shell where they extend as primary rods. Primary rods can be traced the length of one or two pore frames before they diffuse into pore network. Pores are rounded and irregularly shaped, ranging from three to eight microns diameter. Secondary spines are slender rods that are approximately 25% the length and thickness of the primary spines. Secondary spines are commonly broken, giving cortical shell a nodose appearance.

Comparison.—*Pseudorotasphaera* (?) *rotunda* bears a strong resemblance to *Rotasphaera robertsorum*, n. sp. due to its round outline and the well developed pore framework in the latter. It is distinguished by having primary spines that are more tapered and proximally grooved. This species is questionably assigned to *Pseudorotasphaera* because no specimens were found which adequately show the internal structure.

Measurements.—See Table 16.

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—(L.) *rotundus* = round.

Designation of types.—Holotype USNM 466300, paratype TMM 1843TX1.

Range and occurrence.—Silurian, upper Zone 2 and Zone 3 of the Marathon uplift, west Texas.

Superfamily **SPONGODISCACEA** Haeckel,
emend. Pessagno, 1971

Subsuperfamily **PSEUDOAULOPHACILAE** Riedel,
emend. Pessagno, 1971

Family **SPONGURIDAE** Haeckel,
emend. Pessagno, 1973

Type genus.—*Spongurus* Haeckel, 1887

Remarks.—This family includes genera with a spongy shell that is ovate or subcircular in shape and consists

Table 17.—Measurements (in μm) of *Pseudospongoprunum* (?) *tauersi*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
axial diameter cortical shell	176	158	186	(7)
equatorial diameter cortical shell	153	130	177	(7)
length long apical spine	83	74	93	(7)
length short apical spine	60	42	65	(7)

of multiple concentric spongy layers. This group is distinguished from the spongy Astroentactiniinae Nazarov, 1975 (such as *Copiellintra* Nazarov and Ormiston, 1985 and *Copicyntra* Nazarov and Ormiston, 1985) because no rays prevail through layers from center to the outer edge of the cortical shell.

Genus **PSEUDOSPONGOPRUNUM**,
Wakamatsu *et al.*, 1990

Type species.—*Pseudospongoprunum sagittatum*, Wakamatsu *et al.*, 1990

Description.—Subspherical to ovate shell spongy shell with two polar spines. Spongy structure filling the inside of the shell may show weak concentric layering. Two robust spines of unequal length protrude from each pole occurring at an angle near 180 degrees. A ring of 12 to 15 collar pores appear at base of spines. Shallow grooves, termed collar grooves, originate at base of spine at every third or fourth collar pore and run part way up the spine. Presence of grooves at base of spine creates a slight constriction at its juncture with the body of the shell.

Remarks.—The original description of *Pseudospongoprunum* states that the spongy infilling lacks symmetric structures, yet in the species description of *P. sagittatum*, the authors note that a faint layered structure is rarely observed in the central part of the shell. Therefore, forms that possess concentric spongy layering are tentatively included herein. *Pseudospongoprunum* can be distinguished from the genus *Copiellintra* Nazarov and Ormiston, 1985 by lacking a central latticed sphere and possessing well developed polar spines, and from *Spongocoelia* Hinde, 1899 and *Praespongocoelia*, n. gen. by lacking an internal cavity. *Pseudospongoprunum* also bears a strong resemblance to Archaeospongopruniinae Pessagno, 1973 but has thicker, more evenly tapered spines that are grooved only at the proximal end.

Pseudospongoprunum* (?) *tauersi, new species
Plate 7, figures 13–15

Diagnosis.—Shell ovate consisting of eight or nine concentric spongy layers. A small hollow appears at center, approximately 20% the diameter of the short

dimension of the shell. Two robust spines emerge from poles at an angle of approximately 175 degrees. The longer of the two spines is slightly shorter than the long axis of the cortical shell. Spines are conical and highly tapered. Collar grooves are pronounced and extend no further than half way up the spine.

Comparison.—This species bears superficial resemblance to *Praespongocoelia parvus* Furutani, 1990 but may be distinguished by having a different wall structure and spine morphology. *Pseudospongoprunum* (?) *tauersi* has multiple concentric spongy layers and a coarser spongy meshwork (larger pores) than the *Praespongocoelia* spp. The spine length is shorter with respect to the length of the spongy cortical shell and spines taper more distally. *Pseudospongoprunum* (?) *tauersi* bears strong resemblance to *Pseudospongoprunum sagittatum* Wakamatsu *et al.*, 1990, but differs in that the spongy meshwork is slightly looser in *Pseudospongoprunum sagittatum* and the concentric spongy layering is more pronounced in *Pseudospongoprunum* (?) *tauersi*.

Measurements.—See Table 17.

Type locality.—Monument Creek, Marathon uplift, west Texas.

Etymology.—This species is named in honor of Dr. Peter Tauvers for his contributions to the geology of the Marathon uplift.

Designation of types.—Holotype USNM 466301, paratype TMM 1858TX1.

Range and occurrence.—Late Silurian, Zone 6 of the Marathon uplift, west Texas, ? Kurosegawa Tectonic Zone, Japan.

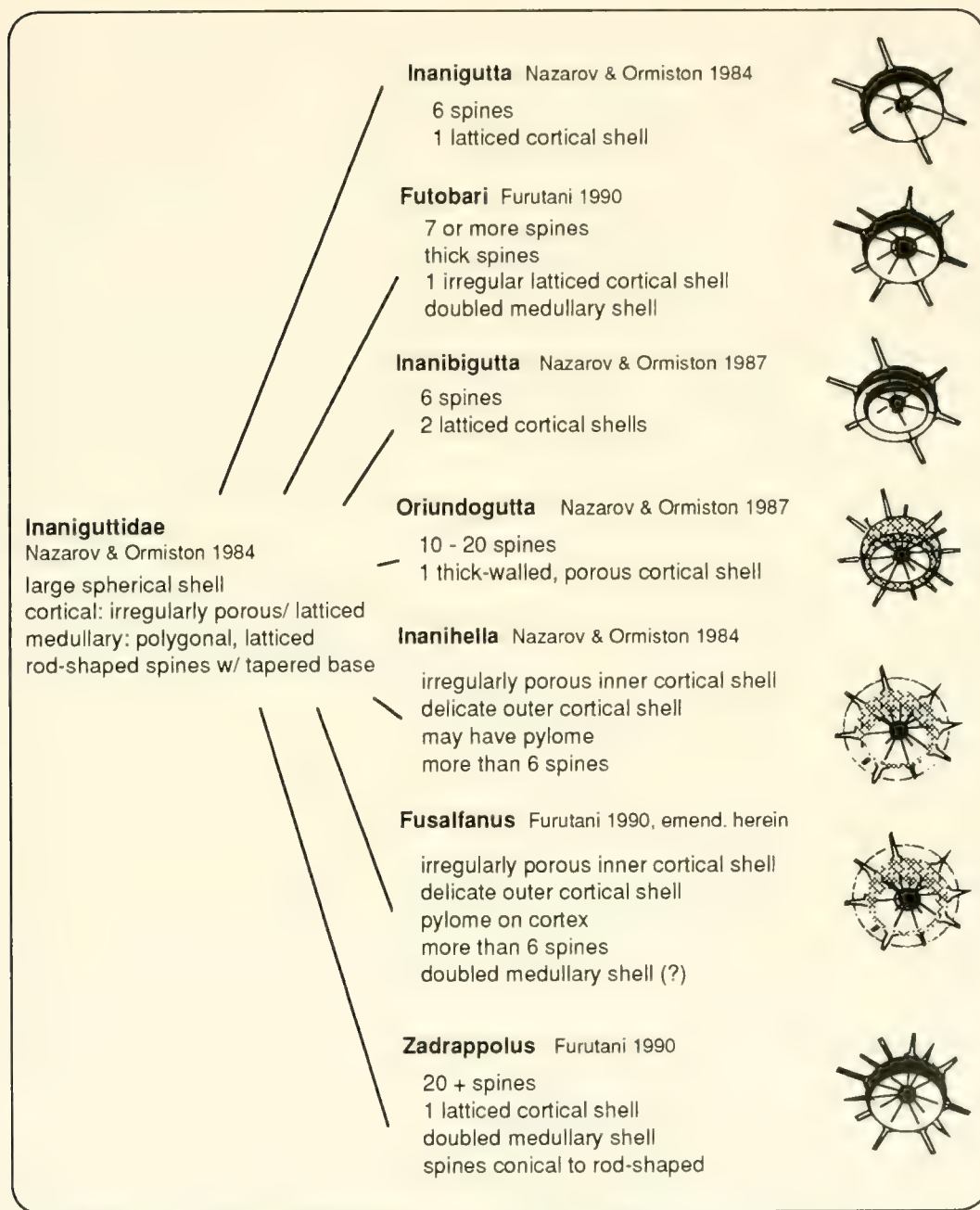
Genus **DEVONIGLANSUS** Wakamatsu *et al.*, 1990

Type species.—*Devoniglans unicus* Wakamatsu *et al.*, 1990

Devoniglans unicus Wakamatsu *et al.*, 1990
Plate 7, figures 16–20

Description.—Ellipsoidal shell consisting of multiple concentric spongy layers, an apical spine, and a basal pylome which is surrounded by multiple basal spines.

Remarks.—The genus *Devoniglans* Wakamatsu *et al.* is a good example of why the incorporation of age names into species names can be problematic. This distinctive taxon was originally described from the Yokokura-yama area of the Kurosegawa Tectonic Zone, Japan. The authors had no precise age control, but presuming the sample to be Devonian, incorporated the age term into the generic name. Conodonts show that *Devoniglans unicus* ranges no higher than Late Silurian age in the Marathon uplift. The last occurrence of *D. unicus* is below the top of the *Devoniglans unicus*–*Pseudospongoprunum* (?) *tauersi* Zone, which



Text-figure 10.—Schematic diagram of the genera in the family Inaniguttidae Nazarov and Ormiston, 1984.

is no younger than Pridolian and is overlain by several additional meters of Silurian strata. The age of the *D. unicus* assemblage in the Kurosegawa Tectonic Zone was made from inference and unless independent geochronologic data can demonstrate that *D. unicus* ranges considerably higher in Japan than in the Marathon uplift, it is presumed to be restricted to the Silurian.

Range and occurrence.—Late Silurian, *Devoniglan-sus unicus* assemblage of Kurosegawa Tectonic Zone, Japan; lower half of Zone 6 of the Marathon uplift, west Texas.

Superfamily INCERTAE SEDIS

Family INANIGUTTIDAE Nazarov and Ormiston, 1984, emended herein

Type genus.—*Inanigutta* Nazarov and Ormiston, 1984

Emended diagnosis.—Spumellarians with one or more cortical shells that are irregularly porous to latticed, and a latticed subspherical medullary shell. Primary bars extend from primary spines on the cortical shell to the surface of the medullary shell, where they

branch into four or more rays that are incorporated into the medullary lattice. Primary spines are generally rod-shaped, but have four to six grooves at the base and are tapered proximally. The grooves occur in between blades which are contiguous with pore frames at the base of the spine.

Remarks.—The Inaniguttidae are a biostratigraphically important Silurian group. In the Marathon uplift, they become increasingly abundant up-section and comprise the majority of the assemblages in Zones 4 through 7. The Inaniguttidae are distinguished from the other major group of spherical Spumellariina, Entactiniidae Riedel (1967), by the absence of an internal spicule, and from the Paleoactinosphaeridae, n. fam. by being larger with rod-shaped spines which are tapered and grooved only at the base. The cortical shell is commonly thickened, consisting of a three-dimensional network of coarse, irregularly shaped, subrounded pore-frames which, in some forms, approach a spongy texture with an irregular, three dimensional array of pores (e.g., *Fusalfanus osobudaniensis* Furutani, 1990). Late taxa placed in the Inaniguttidae (e.g., *Oriundagutta* (?) *varispina*, n. sp.) exhibit a thick but more organized pore framework where the pores penetrate from the inner to the outer side of the cortical shell perpendicular to the shell wall. In earlier forms (e.g., *Inanihella* sp. A), the pores penetrate from inside to outside of cortical shell in a tortuous pathway not perpendicular to the shell wall. Although the degree of organization of the cortical shell appears to be different between earlier and later forms, all are large taxa possessing a similar subrounded to polygonal latticed medullary shell and similar primary spine morphology.

In highly spinose forms, the lattice shell appears highly three-dimensional due to the mode of attachment of the spine bases to the cortical shell. Spine bases are characteristically grooved and highly tapered. The bars occurring in between the grooves branch out and are contiguous with adjacent pore frames. This gives the pore frames a three-dimensional, spiked appearance (e.g., *Zadrappolous spinosus* Furutani, 1990). Therefore, the sphericity of the cortical shell surface appears largely controlled by the abundance of spines. The taxa included in the Inaniguttidae and a brief description of their characteristics appear in Text-figure 10.

Genus **INANIELLA** Nazarov and Ormiston, 1984, emended herein

Type species.—*Helioentactinia bakanasensis* Nazarov 1980, emend. Nazarov, 1988

Emended diagnosis.—Two attached latticed or irregularly porous cortical shells surround a spherical latticed medullary shell. The outer cortical shell is del-

icate. Multiple rod-shaped primary bars emerge from medullary shell and extend past cortical shell to form primary spines. Base of primary spines may be grooved.

Remarks.—The emended diagnosis differs from the original in that it restricts the genus to those taxa possessing two latticed cortical shells. The type species possesses two latticed cortical shells, yet another species previously classified under this genus, *Inanihella macroacantha* Rüst, emended Nazarov (1988), does not and is provisionally reassigned to the genus *Oriundogutta* Nazarov, 1988.

***Inanihella* sp. A**

Plate 5, figure 16

Description.—Large irregularly porous cortical shell consisting of two interconnected layers. Outer layer is delicate. Latticed spherical medullary shell. Multiple thin rod-shaped spines (25 or more per hemisphere) extend from cortical shell.

Remarks.—This distinct taxon was found in only one sample and was not in sufficient abundance to describe formally.

Range and occurrence.—Late Silurian, Zone 3 of the Marathon uplift, west Texas.

Genus **FUSALFANUS** Furutani, 1990, emended herein

Type species.—*Fusalfanus osobudaniensis* Furutani, 1990

Emended diagnosis.—Coarsely porous inner cortical shell which may possess a pylome. A delicate outer cortical shell is developed outside the coarsely porous, delicate cortical shell, but is rarely preserved. Medullary shell is latticed. More than six spines per hemisphere on cortical shell. Spines are strongly tapered proximally and may be grooved at proximal end.

Remarks.—Whereas the delicate outer cortical shell is seldom preserved, remnants are commonly seen on the distal ends of the primary spines giving the spines a trident-shaped appearance. No pylomes were found on the Marathon uplift specimens, yet most specimens were damaged or recrystallized on one area of the cortical shell, allowing for the possibility that a pylome may have been present but is no longer preserved.

This genus was originally distinguished from *Inanihella* Nazarov and Ormiston, 1984, by possessing a spongy inner cortical shell, whereas *Inanihella* possesses a coarsely porous cortical shell. The wall structure of the type *Fusalfanus* material, however, appears to agree with *Inanihella* and is more accurately described as coarsely porous. *Fusalfanus* appears to share all of the characteristics of *Inanihella* except for its medullary shell, which is described as a doubled lattice wall. Photos of the medullary structure of the type specimens are not sufficiently explicit, however, to show

the doubled wall. *Fusalfanus* should possibly be treated as a junior synonym for *Inanihella*, but further study of the type material of both *Fusalfanus* and *Inanihella* is needed before a reclassification can be made.

***Fusalfanus osobudaniensis* Furutani, 1990**
Plate 5, figures 15, 17, 18; Plate 9, figure 1

?*Inanihella tarangulica* Nazarov and Ormiston, 1984, p. 73, pl. IV, figs. 3, 4.

Description.—Thick coarsely porous inner cortical shell with traces of a more delicate outer cortical shell and well developed spines. Traces of this outer shell give primary spines a trident-shaped or crown-shaped appearance. A pylome is present on the inner cortical shell. Spines number approximately 15 to 20 on a hemisphere and are grooved at base. Five to six grooves alternate with blades that connect to pore frames at the base of the spine.

Remarks.—*Fusalfanus osobudaniensis* in the Caballos samples possess the spongy inner cortical shell (Pl. 9, fig. 1), yet no specimens preserving the medullary structure were found. Traces of the delicate outer cortical shell are present.

Range and occurrence.—Silurian, Zones 1 and lower Zone 2 of the Marathon uplift, west Texas; *Fusalfanus osobudaniensis* Zone of the Fukuji Area, Gifu Prefecture, Japan.

Genus ORIUNDOGUTTA Nazarov, 1988

Type species.—*Oriundogutta ramificans* (Nazarov), 1985

Description.—One porous thick-walled cortical shell surrounds a polygonal to hemispherical medullary shell. Eight to 20 or more spines radiate from cortical shell.

***Oriundogutta* (?) *kingi*, new species**
Plate 6, figures 1, 4

Inanihella macroacantha Rüst, 1892, Nazarov, 1988, p. 209, pl. XII, fig. 1.

Inanihella macroacantha? Rüst, 1892, Nazarov and Ormiston, 1993, p. 34, pl. 2, figs. 6–8.

Diagnosis.—One thick cortical shell with 15 to 20 long robust spines per hemisphere. Spines are highly tapered at proximal end and contain four to five prominent grooves alternating with ridges. Spine cross section at proximal end is quadradial to pentaradial and medially to distally is circular. Shell is large (ave. 180 microns in diameter). Pore frames are subcircular and thick. Pores measure an average of eight microns in diameter. Medullary shell is polygonal and latticed, connected to cortical shell by rod-shaped primary bars.

Remarks.—Since there is no trace of a delicate second cortical shell in specimens of *Oriundogutta* (?) *kingi*, it cannot be placed in the genus *Inanihella*. *Oriundogutta* (?) *kingi* fits the generic description of *Oriundogutta*

Table 18.—Measurements (in μm) of *Oriundogutta* (?) *kingi*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
cortical shell diameter	176	140	200	(7)
width spine at base	26	24	29	(7)
width spine at midspine	16	14	18	(6)

iundogutta Nazarov, 1988, which describes a single thick, porous cortical shell. It is only provisionally placed in the genus, however, because the photograph of the type species is out of focus and morphologic details, like pore shape and spine structure are not discernable.

The figured specimen of *Inanihella* (*Acanthosphaera*) *macroacantha* Rüst, 1892 (Nazarov, 1988, pl. XII, fig. 1) appears to be conspecific with *O.* (?) *kingi* and is synonymized herein. *Oriundogutta* (?) *kingi*, n. sp. is not the same species, however, as *Acanthosphaera macroacantha* Rüst, 1892. *Acanthosphaera macroacantha* Rüst (Rüst, 1892, p. 147, pl. XIII, fig. 2), described from the Silurian of Cabrieres, possesses a single shell and the drawing, although fairly nondescript, shows only one shell. I therefore disagree with Nazarov and Ormiston's identification. The specimen identified as *Inanihella macroacantha* by Nazarov and Ormiston (1988, 1993) is not *A. macroacantha* Rüst. Furthermore, *A. macroacantha* Rüst does not fit the generic description of *Inanihella* Nazarov and Ormiston, 1984 and should not have been transferred into the genus *Inanihella*.

Comparison.—*Oriundogutta* (?) *kingi* is distinguished from *Oriundogutta* (?) *varispina*, n. sp. by possessing more spines per hemisphere and by possessing spines of equal length.

Measurements.—See Table 18.

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—This species is named in honor of P. B. King for his pioneer contributions to the geology of the Marathon uplift.

Designation of types.—Holotype USNM 466302, paratype TMM 1851TX1.

Range and occurrence.—Silurian, Zones 2 through 5 of the Marathon uplift, west Texas, southern Urals, Kazakhstan.

***Oriundogutta* (?) *varispina*, new species**
Plate 6, figures 2, 3; Plate 9, figure 4

Diagnosis.—Large, thickened latticed cortical shell surrounding irregularly shaped medullary shell. Six or more thick, robust spines are interspersed with six or more thinner, smaller spines on cortical surface. Robust spines are grooved at the base and highly tapered.

Table 19.—Measurements (in μm) of *Oriundogutta* (?) *varispina*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
diameter cortical shell	212	178	270	(8)
diameter medullary shell	49	46	56	(7)
avg. width large spine base	56	43	65	(9)
avg. width short spine base	15	10	23	(5)
thickness cortical shell	21	14	25	(8)

Comparison.—Pore framework of the cortical shell appears to be slightly more organized than the pores present on *Oriundogutta* (?) *kingi*, n. sp. Robust spines have a very similar morphology to spines on *Oriundogutta* (?) *kingi* (Pl. 9, fig. 4) but are more massive and fewer in number.

Measurements.—See Table 19.

Type locality.—Monument Creek, Marathon uplift, west Texas.

Etymology.—(L.) *varius* = varied, *spina* = spine.

Designation of types.—Holotype USNM 466303, paratype TMM 1858TX2.

Range and occurrence.—Late Silurian, Zone 6 in the Marathon uplift, west Texas.

Genus **ZADRAPPOLUS** Furutani, 1990

Type species.—*Zadrappolus yoshikiensis* Furutani, 1990

Description.—Inaniguttids with single latticed cortical shell and doubled medullary shell having ten or more spines per hemisphere. Spines may be rod-shaped, needle-shaped, or conical.

Zadrappolus yoshikiensis Furutani, 1990

Plate 6, figures 14–16

Description.—Spherical, latticed cortical shell with regularly shaped rounded pores. Spines are well tapered at the base and possess deep grooves which extend distally nearly halfway up the spine. Spines strongly tapered at base and number 10 to 15 per hemisphere.

Range and occurrence.—Silurian, *Zadrappolus yoshikiensis* assemblage of the Fukuji Area, Japan; Zones 2 through 5 of the Marathon uplift, west Texas.

Zadrappolus spinosus Furutani, 1990

Plate 6, figure 6; Plate 9, figures 9, 11

Description.—Spherical, single latticed cortical shell with numerous (80 or more) cylindrical spines. Spines are slender and tapered near the base.

Comparison.—*Zadrappolus spinosus* can be distinguished from other species of *Zadrappolus* by possessing numerous slender spines.

Range and occurrence.—Silurian, *Spongocoelia parvus*–*S. kamitakarensis* assemblage, Fukuji Area, Ja-

Table 20.—Measurements (in μm) of *Zadrappolus lunaris*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
diameter cortical shell	168	158	183	(6)
diameter medullary shell	43	39	48	(4)
avg. spine length	38	34	43	(7)
avg. width spine base	17	12	22	(7)

pan; Zones 1 through 3 of the Marathon uplift, west Texas.

Zadrappolus tenuis Furutani, 1990

Plate 6, figures 10, 12, 13

Description.—Thick spherical latticed cortical shell with 20 to 25 spines visible per hemisphere. Spines are long and cylindrical but strongly tapered at proximal end with three grooves near base.

Range and occurrence.—Late Silurian, *Zadrappolus yoshikiensis* assemblage, Fukuji Area, Japan; Zones 3 to 6 of the Marathon uplift, west Texas.

Zadrappolus sp. aff. **tenuis** Furutani, 1990

Plate 6, figure 11

Description.—This form is very similar to *Zadrappolus tenuis* Furutani, 1990 but differs in being slightly larger and having more robust, less tapered spines.

Range and occurrence.—Silurian, Zone 2 of the Marathon uplift, west Texas.

Zadrappolus lunaris, new species

Plate 6, figures 7, 8; Plate 9, figure 8

Diagnosis.—Large, spherical latticed cortical shell with approximately 10 spines per hemisphere. Spines short, conical, and tapered distally. Spine bases are approximately 15 to 20 microns in diameter and have five to six alternating grooves and ridges which are approximately 50% of the spine length. Distal half of spines are rod-shaped and circular in cross section. Medullary shell is latticed and polygonal, connected to cortical shell by non-tapering rod-shaped bars. Pore frames are irregularly polygonal, varying from diamond-shaped to pentagonal, and measure five to eight microns diameter.

Comparison.—*Zadrappolus lunaris* can be distinguished from other species of *Zadrappolus* by having shorter, fewer spines.

Measurements.—See Table 20.

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—(L.) *lunaris* = of the moon.

Designation of types.—Holotype USNM 466304, paratype TMM 1853TX1.

Range and occurrence.—Late Silurian, Zone 6 of the Marathon uplift, west Texas.

Zadrappolus sp. A

Plate 6, figure 9

Description.—Latticed cortical shell with 20 or more spines per hemisphere. Spines are tapered and short with four to five grooves at base. Grooves extend nearly halfway up spine.

Comparison.—This species bears close resemblance to *Z. lunaris* n. sp. but can be distinguished by having nearly twice as many spines. An insufficient number of specimens were recovered to formally describe this taxon.

Range and occurrence.—Silurian, Zone 2 of the Marathon uplift, west Texas.

Family **PALAEOACTINOSPHAERIDAE**,
new family

Type genus.—*Palaeoactinosphaera*, new genus

Diagnosis.—Spherical Spumellarians with two concentric shells, the cortical and medullary shells. The cortical shell is a latticed sphere and the medullary shell is a latticed polygon or sphere. Six to nine primary spines extend from cortical shell. Spines may be conical, straight rods, bladed, or grooved.

Remarks.—The palaeoactinosphaerids comprise a significant part of the Caballos assemblages. These taxa represent between 10 to 50% of the specimens in a given assemblage. Presence or absence of secondary spines distinguishes the two genera within.

Genera included.—*Palaeoactinosphaera*, *Stylactinosphaera*.

Range and occurrence.—Silurian of the Marathon uplift, west Texas.

Genus **PALAEOACTINOSPHAERA**, new genus

Type species.—*Palaeoactinosphaera antica*, new species

Diagnosis.—Spherical to subspherical latticed cortical shell with six to eight primary spines and no secondary spines. Primary spines may be rod-shaped, grooved, or bladed, and can be arranged either perpendicular (orthogonally) or non-perpendicular (eccentrically) to each other. Primary bars extend inward and connect the cortical shell to the medullary shell. Primary bars are rod-shaped or three-bladed. Pore frames on cortical shell are polygonal to subcircular in outline and vary in their degree of regularity. Short nodes always occur at the juncture of pore frames, but are sometimes not well-preserved. Medullary shell may be either spherical or subspherical.

Remarks.—Taxa assigned to this genus possess both orthogonally arranged and eccentrically arranged primary spines. This difference in spine arrangement could be considered by some as a generic level distinction, however sufficient similarity exists in cortical wall structure and spine morphology to warrant assignment within the same genus. These forms had been informally grouped under the term “Palaeoactinommid” *sensu* Holdsworth (1977), a term originally coined to encompass all spherical Spumellariina that did not fall into either the rotasphaerid informal group or Entactinacea Riedel, 1967. *Palaeoactinosphaera* bears external resemblance to *Paleosphaera* Renz, 1990 but can be distinguished by the presence of a medullary shell, whereas *Paleosphaera* consists of a cortical shell and has no medullary shell. *Palaeoactinosphaera* also bears a strong resemblance to *Entactinosphaera* Foreman, 1963, of Devonian age and younger. Both have regularly latticed cortical and medullary shells and both possess a diverse primary spine morphology that includes bladed and grooved spines. *Entactinosphaera* differs in that it possesses an internal spicule within the medullary shell. I have searched for an internal spicular structure in all representative species of *Palaeoactinosphaera* and have found no structure present. Furthermore, early representatives of the *Palaeoactinosphaera*, such as *P. asymmetrica*, n. sp. (Pl. 4, fig. 13), have an irregularly shaped medullary shell which appears to be a coalescence of branching rays emanating from the base of the primary bars. This manner of medullary shell construction resembles the mode of cortical wall construction observed in the Rotasphaeriacea and the medullary shell construction of the Inaniguttids. The branching medullary shell structure has also been described by Goodbody (1986) in the general grouping he refers to as the “Palaeoactinommid.”

Biostratigraphically, *Palaeoactinosphaera* is not as useful as Rotasphaeridae, n. fam. and Inaniguttidae Nazarov and Ormiston, 1984. A few species, such as *P. elegantissima*, n. sp. and *P. crucispina*, n. sp., are short-ranging and are locally useful as secondary marker taxa, yet others, such as *P. antica*, n. sp., are longer ranging. Additionally, the external morphology of *Palaeoactinosphaera* strongly resembles some Devonian *Entactinosphaera* and these similarities may make it difficult to distinguish between the two. *Palaeoactinosphaera* is distinguished from genera of the Inaniguttidae by having a latticed cortical shell with more regularly shaped pores, nodes at pore frame junctures, fewer spines, and spines that may be bladed.

Range and occurrence.—Silurian, Zone 1 through Zone 6 of the Marathon uplift, west Texas; Cape Phillips Formation of the Canadian Archipelago.

Table 21.—Measurements (in μm) of *Palaeoactinosphaera antica*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
diameter cortical shell	103	92	113	(5)
diameter medullary shell	78	70	86	(2)
avg. spine length	44	37	52	(5)
avg. width spine base	21	17	25	(5)

***Palaeoactinosphaera antica*, new species**

Plate 4, figures 15–17

Diagnosis.—Spherical cortical shell with polygonal to subrounded pore frames. Pore frames exhibit nodes at junctures, are six to nine microns in diameter, and are of moderately uniform size. Six stubby, blunt-ended primary spines are arranged orthogonally. Primary spines are rod-shaped and slightly tapered at distal end with six poorly developed grooves at base which extend no further than 25% of the way up the spine. Primary spines are of equal length, equal to approximately 50% of the cortical shell diameter. Subcircular medullary shell is latticed and its diameter is approximately 70% of the cortical shell diameter.

Comparison.—*Palaeoactinosphaera antica* is distinguished from the other *Palaeoactinosphaera* by having shorter, thinner, rod-shaped spines with less prominent grooves.

Measurements.—See Table 21.

Type locality.—East Bourland Mountain, Marathon uplift, west Texas.

Etymology.—(L.) *anticus* = foremost, ancient.

Designation of types.—Holotype USNM 466305, paratype TMM 1847TX1.

Range and occurrence.—Silurian, Zones 1 through 5 of the Marathon uplift, west Texas.

***Palaeoactinosphaera asymmetrica*, new species**

Plate 4, figures 12–14

Diagnosis.—Latticed subspherical cortical shell with six to seven spines arranged eccentrically. Spines range from 45 to 60% of cortical shell diameter and are of varying lengths. Spines are conical, robust, blunt-ended, and have five to six grooves and alternating ridges at the base. Grooves and ridges extend 25 to 35% of the way up the spine and are of unequal size. Medullary

Table 22.—Measurements (in μm) of *Palaeoactinosphaera asymmetrica*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
diameter cortical shell	147	104	205	(8)
diameter medullary shell	42	40	45	(3)
avg. spine length	67	56	76	(7)
avg. width spine base	35	30	40	(8)

Table 23.—Measurements (in μm) of *Palaeoactinosphaera barricki*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
diameter cortical shell	87	82	91	(6)
avg. width spine base	18	17	19	(6)
avg. spine length	55	52	59	(6)
avg. width spine grooves at base	13	10	15	(6)
avg. width spine ridges	3	2.5	3	(6)

shell is latticed and subcircular with a diameter approximately one-third of the cortical shell diameter. Pores are subrounded to polygonal and but are of a uniform size range of five to eight microns diameter. Nodes occur at pore frame junctures.

Comparison.—*Palaeoactinosphaera asymmetrica* can be distinguished from other *Palaeoactinosphaera* by its subcircular shape and its robust, conical spines of unequal size.

Measurements.—See Table 22.

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—(Gr.) *asymmetros* = without symmetry.

Designation of types.—Holotype USNM 466306, paratypes TMM 1841TX2, TMM 1842TX1, TMM 1846TX1.

Range and occurrence.—Silurian, Zones 1 and 2 of the Marathon uplift, west Texas.

***Palaeoactinosphaera barricki*, new species**

Plate 4, figures 8, 9

Diagnosis.—Latticed cortical shell with six eccentrically arranged primary spines. Spines are robust, tapered, and have four deep grooves alternating with four prominent blades that extend the entire spine length. The grooves are three to four times as wide as the blades. At spine base, grooves penetrate cortical shell to form pores, and ridges bifurcate to converge with the pore frames on the cortical shell. Pore frames are of non-uniform shape and size, ranging from three to ten microns diameter; two adjacent pore frames may vary as much as 50% in size. Pore frames are generally subrounded and nodes occur at pore frame triple-junctures. Primary spines are of slightly unequal size and their length ranges from 50 to 75% of the cortical shell diameter. Thin, rod-shaped primary bars connect cortical shell to latticed medullary shell. Medullary shell is latticed, subspherical, and its diameter approximately 40% of the cortical shell diameter.

Comparison.—This species is distinguished from *Palaeoactinosphaera elegantissima* n. sp. by having primary spines with deeper, wider grooves, and by having pore frames with a non-uniform shape and size.

Measurements.—See Table 23.

Table 24.—Measurements (in μm) of *Palaeoactinosphaera* (?) *crucispina*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
diameter cortical shell	190	167	196	(9)
diameter medullary shell	75	72	76	(3)
avg. spine width	31	24	34	(9)
avg. width spine groove	7.5	7	8	(9)
avg. width spine blade	9	9	10	(9)

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—This species is named in honor of Dr. Jim Barrick for his contributions to improving the chronostratigraphic control of the Caballos Novaculite.

Designation of types.—Holotype USNM 466307, paratype TMM 1842TX2.

Range and occurrence.—Silurian, Zones 1? through 3 of the Marathon uplift, west Texas.

***Palaeoactinosphaera* (?) *crucispina*, new species**

Plate 5, figures 11, 12; Plate 9, figure 5

Diagnosis.—Large, spherical latticed cortical shell with large, thickened subcircular pores of varying size. Nodes occur on pore-frames at pore triple-junctures. Six robust, three-bladed spines with deep grooves are arranged orthogonally. Spines are long, non-tapering and triaxial in cross section. Latticed medullary shell is subquadrate with large irregularly shaped pores. Three-bladed primary bars with a triaxial cross section connect medullary shell to cortical shell. Primary bars branch at base and anastomose into pore-frames of medullary shell (Pl. 5, fig. 12). Medullary shell is approximately 50% the diameter of cortical shell.

Remarks.—*Palaeoactinosphaera* (?) *crucispina* is a large, robust form which is very distinct due to its large pores and long bladed spines. The pore frames are nodose and subcircular in shape, yet they are substantially larger than the pores in other species of *Palaeoactinosphaera* (roughly twice the diameter). The long, nontapering bladed spines are more similar to the bladed spines found in Devonian Entactiniidae Riedel, 1967 than to the spine morphology found in other *Palaeoactinosphaera*, yet the internal spicule characteristic of Entactiniidae was not observed in this species.

Measurements.—See Table 24.

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—(L.) *crucis* = cross, *spina* = spine.

Designation of types.—Holotype USNM 466308, paratypes TMM 1846TX2, TMM 1856TX1.

Range and occurrence.—Silurian, Zone 1 and lowermost Zone 2 of the Marathon uplift, west Texas.

Table 25.—Measurements (in μm) of *Palaeoactinosphaera* *elegantissima*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
diameter cortical shell	126	115	130	(7)
avg. spine length	70	63	73	(7)
avg. width spine base	35	33	36	(7)
avg. width spine groove at base	7	6	7	(7)
avg. width spine ridge	8	8	8	(7)

***Palaeoactinosphaera* *elegantissima*, new species**

Plate 4, figures 10, 11

Diagnosis.—Latticed cortical shell with pentagonal to subrounded pore frames and six robust primary spines. Pores are fairly uniform in shape and size ranging from three to eight microns diameter. Nodes occur on pore frames at pore triple-junctures. Spines possess five to six grooves and alternating ridges which extend the length of the spine. Spines are more strongly tapered at distal ends, giving a bullet-shaped appearance. Grooves are deep yet narrow and alternate with rounded ridges which are of approximately equal width to the grooves. All primary spines are of equal length, equal to approximately 60% of the cortical shell diameter. Rod-shaped primary bars connect cortical shell to subspherical latticed medullary shell with a diameter of approximately 35% of cortical shell diameter.

Comparison.—This species is distinguished from *P. asymmetrica*, n. sp. by possessing narrowly grooved spines which are of equal length, by having larger pore frames, and a more circular cortical shell. It also can be distinguished from *P. barricki*, n. sp. by possessing more narrowly grooved spines, spines of equal length, and more uniform pore frames.

Measurements.—See Table 25.

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—(L.) *elegantissimus* = very fine, choice.

Designation of types.—Holotype USNM 466309, paratypes TMM 1850TX5, TMM 1848TX1.

Range and occurrence.—Silurian, lower half of Zone 2 of the Marathon uplift, west Texas.

***Palaeoactinosphaera* (?) *octaspina*, new species**

Plate 4, figure 7; Plate 9, figure 3

Diagnosis.—Latticed spherical cortical shell with pentagonal to subrounded pore frames and eight slender primary spines. Pores are fairly uniform in shape and size ranging from five to seven microns diameter. Nodes occur on pore frames at pore triple-junctures. Primary spines of equal length, equal to approximately half of the cortical shell diameter. Spines are slightly tapered and circular in cross section, except at base which is tetradial in cross section due to four collar

Table 26.—Measurements (in μm) of *Palaeoactinosphaera* (?) *octaspina*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
diameter cortical shell	139	125	149	(7)
diameter medullary shell	54	52	56	(2)
avg. spine length	49	45	54	(7)
avg. width spine base	12	9	14	(7)

pores which extend up the spine to form four grooves and alternating ridges. Grooves and ridges extend distally no further than 10% of the spine length. Primary spines are of approximately equal length, equal to approximately 35 to 40% of the cortical shell diameter. Rod-shaped primary bars connect cortical shell to latticed spherical medullary shell. Diameter of medullary shell is approximately 40% cortical shell diameter.

Remarks.—This species is placed in *Palaeoactinosphaera*, n. gen. only tentatively because the medullary shell is spherical. Other *Palaeoactinosphaeridae* have a subspherical medullary shell; *P. (?) octaspina* is a late species, however, and increased sphericity of the medullary shell may be a derived characteristic. A spherical medullary shell is a common characteristic in *Entactinosphaera* Foreman, 1963, and since the inside of the medullary shell was observed in only one specimen it is possible that *P. (?) octaspina* is an *Entactinosphaera* whose internal spicule has not been preserved.

Comparison.—This species is distinguished from *Palaeoactinosphaera antica*, n. sp. by possessing eight spines which are thinner and slightly longer. It may be distinguished from *Palaeoactinosphaera asymmetrica*, n. sp. by having a more circular outline, more slender spines, and pore frames which are more uniform in shape and size.

Measurements.—See Table 26.

Type locality.—East Bourland Mountain, Marathon uplift, west Texas.

Etymology.—(L.) *octo* = eight, *spina* = spine.

Designation of types.—Holotype USNM 466314, paratype TMM 1845TX1.

Range and occurrence.—Late Silurian, upper half of Zone 2 through Zone 6 of the Marathon uplift, west Texas.

Genus **STYLACTINOSPHERA**, new genus

Type species.—*Stylactinosphaera prima*, new species

Diagnosis.—Latticed medullary shell surrounded by thickened, spinose cortical shell with six to eight robust primary spines. Rod-shaped primary bars extend from cortical shell to latticed, subrounded medullary shell. Primary spines are conical with shallow grooves and alternating ridges at proximal end. Grooves and alternating ridges partially extend up the length of the spine.

Table 27.—Measurements (in μm) of *Stylactinosphaera prima*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
diameter cortical shell	185	149	242	(7)
diameter medullary shell	59	56	65	(3)
avg. length primary spine	82	65	93	(7)
avg. length secondary spine	35	28	42	(6)
avg. width primary spine base	34	28	39	(7)

The cortical shell is covered by numerous secondary spines (20 or more per hemisphere) that are less than 75% the size of the primary spines. Grooves and alternating ridges occur at proximal end of secondary spines and partially extend up the spine length.

Remarks.—*Stylactinosphaera* and *Palaeoactinosphaera* have similar primary spine morphology, spine distribution, and medullary shell morphology, but differ in that *Palaeoactinosphaera* possesses numerous secondary spines that substantially alter the appearance of the cortical shell. The secondary spines in *Stylactinosphaera* are numerous and robust so that poor preservation should not completely remove them. Poorly preserved specimens of *Stylactinosphaera* have a thickened cortical shell that has an irregular, bumpy appearance and look distinctly different from *Palaeoactinosphaera*, which has uniform pore frames and delicate nodes.

Range and occurrence.—Silurian, Zone 1 and lower Zone 2 of the Marathon uplift, west Texas.

Stylactinosphaera prima, new species

Plate 4, figures 18, 19

Diagnosis.—Large shell with thickened latticed cortical shell and numerous secondary spines. Secondary spine development gives cortical shell a thickened, irregularly porous appearance and obscures shape and size of pore frames. Eight blunt-ended robust primary spines extend from cortical shell and are grooved at the base. Five to six grooves and alternating ridges extend 25 to 30% of the way up the spine from proximal end. Grooves are not of uniform size, one groove being shorter, thinner, and shallower than the adjacent groove, and ridges are approximately equal width. Secondary spines are numerous (25 or more per hemisphere) and possess the same conical form as the primary spines, but are one-half the length and approximately one-third the thickness. Medullary shell is subspherical and latticed and is approximately 30% the diameter of the cortical shell.

Comparison.—*Stylactinosphaera prima* occurs with *Palaeoactinosphaera asymmetrica*, n. sp. and has a similar primary spine structure and polygonal medullary shell. It differs by possessing a thickened cortical

shell and by possessing numerous robust secondary spines.

Measurements.—See Table 27.

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—(L.) *primus* = first.

Designation of types.—Holotype USNM 466310, paratype TMM 1846TX3.

Range and occurrence.—Silurian, Zone 1 and lower Zone 2 of the Marathon uplift, west Texas.

Family **PALAEOSCENIDIIDAE** Riedel, 1967, emended Holdsworth, 1977, emended Furutani, 1990

Genus **GOODBODIUM** Furutani, 1990

Type species.—*Palaeoscenidium flammatum* Goodbody, 1986

Goodbodium sp. indet.

Plate 5, figures 5, 6

Description.—Test possesses four basal spines and four apical spines. Tent-like layer skirts the upper part of the basal spines.

Remarks.—Specimens observed were poorly preserved. The seemingly solid wall of the tent-like layer may be caused by quartz overgrowth of spinules and lamellae which make up the less solid tent-like shell layer in the type material of *Goodbodium*.

Range and occurrence.—Silurian, Japan; Canadian Archipelago; the Marathon uplift, west Texas.

Genus **HOLDSWORTHUM** Furutani, 1990

Type species.—*Holdsworthum japonicus* Furutani, 1990

Holdsworthum sp. A.

Plate 5, figure 7

Description.—Two short apical spines and three basal spines. Loose net connects basal spines to form an open conical net. A lateral elongate spine (not preserved in figured specimen) projects from the side of the net and curves downward.

Remarks.—This form possesses a lateral spine and loose netting similar to that in the figured specimens of *Holdsworthum* (Furutani, 1990, pl. 8, figs. 8–10). It differs only in that no lamellae develop in the proximal part of the net to form a solid shell. Only two specimens were recovered; insufficient material to formally describe this taxon.

Family **INCERTAE SEDIS**

Remarks.—Included are the genera *Bipylospongia*, n. gen. and *Praespongocoelia*, n. gen. that do not completely fit the description of any one family. They share

Table 28.—Measurements (in μm) of *Bipylospongia rudosa*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
axial diameter cortical shell	215	177	260	(7)
equatorial diameter cortical shell	180	149	214	(7)
width larger pylome	57	41	68	(5)
width smaller pylome	36	31	45	(5)

characteristics with both Actinommidae and Sponguridae. The genera *Cenosphaera* Ehrenberg, 1854 and *Stylosphaera* Ehrenberg, 1854 are also included. They share characteristics with the Actinommidae (Haeckel) Riedel, 1967, yet Holdsworth (1977) believes that the Paleozoic Actinommids, or 'Paleoactinommids,' are phylogenetically distinct. At present, these taxa are treated as genera *Insertae Sedis*.

Genus **BIPYLOSPONGIA**, new genus

Type species.—*Bipylospongia rudosa*, new species

Diagnosis.—Test ovate consisting of a spongy cortical shell with a hollow internal cavity and no medullary shell. Two pylomes occur; one at each pole which are often unequal in size. Pylomes are surrounded by five to eight spines or flanges of varying size. Cortical surface may or may not be covered with spongy nodes.

Range and occurrence.—Silurian, Zones 1 and 2 of the Marathon uplift, west Texas.

Etymology.—(L.) *bi* = two, *spongia* = sponge (Gr.) *pylo* = orifice.

Bipylospongia rudosa, new species

Plate 7, figures 6–9

Radiolarian genus nova A Noble, 1993b, p. 278, pl. 1, fig. 5.

Diagnosis.—Shell is ovate with two pylomes and covered with coarse spongy nodes. Pylomes are at each pole and are of unequal width. Each pylome is ornamented with five to eight flanged spinose projections. Shell wall is thick and spongy, averaging 15 microns thickness. Shell is hollow in center.

Comparison.—This species can be distinguished from *Devoniglansus unicus* Wakamatsu *et al.*, 1990 by having two pylomes and have a hollow spongy cortical shell, as opposed to the solid spongy cortical shell of *D. unicus*.

Measurements.—See Table 28.

Type locality.—East Bourland Mountain, Marathon uplift, west Texas.

Etymology.—(L.) *rudus* = rough.

Designation of types.—Holotype USNM 466311, paratype TMM 1841TX3.

Range and occurrence.—Silurian, Zones 1 and 2 of the Marathon uplift, west Texas.

Table 29.—Measurements (in μm) of *Praespongocoelia fusiforma*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
axial diameter cortical shell	206	177	233	(9)
equatorial diameter cortical shell	161	149	177	(9)
length long spine	217	177	251	(8)
length short spine	96	84	112	(7)

Genus **PRAESPONGOCOELIA**, new genus

Type species.—*Spongocoelia parvus* Furutani, 1990

Diagnosis.—Large robust subspherical to ovate shell with two robust bipolar spines. Spines are fat, wide, blunt-ended, and of unequal length. Base of spines have collar grooves and are slightly constricted at base. Shell consists of a single thickened layer of spongy cortical shell approximately 15 microns thick. Cortical shell may be ornamented with short hispid projections. Interior of shell is hollow; no internal structure has been observed.

Comparison.—This genus bears a strong superficial resemblance to *Pseudospongoprimum* (?) *tauersi* n. sp. but differs in the wall structure. *Spongovalis* has multiple concentric layers which fill most of the internal part of the shell whereas *Praespongocoelia* has a large internal cavity with only one thickened spongy cortical shell. In the event that the internal structure should be obscured by recrystallization, *Praespongocoelia* can be distinguished by a slightly finer spongy meshwork.

Range and occurrence.—Silurian, *Spongocoelia parvus*—*S. kamitakarensis* Zone of the Fukuji Area, Japan; ? Kurosegawa Tectonic Zone of Japan; Zone 2 of the Marathon uplift, west Texas.

Praespongocoelia parva (Furutani), emended herein Plate 7, figures 1–4

Spongocoelia parvus Furutani, 1990, p. 47, pl. 9, figs. 5–6, pl. 10, fig. 1

Spongocoelia parvus Furutani, Noble, 1993b, p. 278, pl. 1, fig. 6.

Emended diagnosis.—Test subspherical, spines are offset from poles to form an angle approximately 165–170 degrees. Spines are blunt at end. Smaller spine is 30 to 40% shorter than larger spine. Larger spine is slightly shorter than long axis of cortical shell. Collar grooves extend approximately 10% up the spine and form a distinct constriction at base. Internal structure is poorly preserved in these specimens but shell appears to consist of a single thickened layer with a large internal cavity.

Comparison.—This species is distinguished from *Pseudospongoprimum* (?) *tauersi* by having a less elongate cortical shell and slightly longer spines which are not as conical and are blunter at the ends. Size of pores

in spongy cortical shell is slightly smaller than those in *P. (?) tauersi*.

Range and occurrence.—Silurian, Zone 2 of the Marathon uplift, west Texas; Japan.

Praespongocoelia fusiforma, new species Plate 7, figures 11, 12

Spongocoelia sp. nova A Noble, 1993b, p. 278, pl. 1, fig. 7.

Diagnosis.—Test subcircular approaching spindle-shaped, spines are very robust and offset from poles to form an angle approximately 175 degrees. The larger spine is elongate, approximately 3× the length of the smaller spine, and is 10 to 15% longer than long dimension of the cortical shell.

Comparison.—This species is distinguished from species *Praespongocoelia parva* Furutani, 1990 by having a spindle-shaped cortical shell which is slightly smaller, and by its long polar spine.

Measurements.—See Table 29.

Type locality.—East Bourland Mountain, Marathon uplift, west Texas.

Etymology.—(L.) *fusiformis* = spindle-shaped.

Designation of types.—Holotype USNM 466312, paratype TMM 1855TX1.

Range and occurrence.—Silurian, lower part of Zone 2 of the Marathon uplift, west Texas.

Genus **CENOSPHAERA** Ehrenberg, 1854

Type species.—*Cenosphaera plutonis* Ehrenberg, 1854 (by monotypy)

Cenosphaera hexagonalis Aberdeen, 1940 Plate 5, figure 10; Plate 9, figure 2

Cenosphaera aberdeenae Furutani, 1990, p. 51, pl. 11, fig. 8, pl. 12, fig. 9.

Cenosphaera aberdeenae Furutani, Noble, 1993b, p. 278, pl. 1, fig. 9.

Description.—Single latticed shell with large open pores and robust pore frames. Eight short spines protrude and are arranged in pairs.

Remarks.—This taxon occurs in virtually all samples of the Silurian Caballos fauna. It makes its last appearance up-section of the material described in this paper, but does not extend into the Middle and Late Devonian part of the Caballos sections. Slight morphological variations can be seen up-section. Younger specimens occurring in Zones 5 and 6 appear to have longer spines and almost imperceptibly thinner pore frames than specimens from the older zones.

Furutani (1990) proposes *Cenosphaera aberdeenae* as a replacement name for *C. hexagonalis* Aberdeen, 1940. I suspect that Furutani has taken this course of action because he thinks the original photos are sufficiently poor and unclear for *C. hexagonalis* to be

considered *nomen dubium*. Aberdeen's photos are taken from thin-sections and many show only a cross section of the species with little surface detail represented. *Cenosphaera hexagonalis* has a relatively simple shell construction with large, open pores and it is the only species of Aberdeen's that I can identify with certainty. Therefore, the replacement name is not necessary; *C. hexagonalis* is both valid and available.

Range and occurrence.—Silurian, Zones 1 through 6 and younger (see remarks) of the Marathon uplift, west Texas; Canadian Archipelago; Japan.

Genus **STYLOSPHAERA** Ehrenberg

Type species.—*Stylosphaera hispida* Ehrenberg, 1854

Stylosphaera* (?) *magnaspina, new species
Plate 5, figures 2–4

Stylosphaera ? sp. B Furutani, 1990, p. 39, pl. 5, figs. 7, 8.

Stylosphaera ? sp. C Furutani, 1990, p. 40, pl. 6, figs. 1, 2.

? *Stylosphaera quasirobusta* Aberdeen, 1940, p. 135, pl. 21, fig. 5.

Diagnosis.—Spherical to slightly ellipsoidal cortical shell with two robust, grooved, polar spines. Spines are grooved the entire length and are rounded at distal end. Spine diameter is approximately 50% of cortical shell diameter. Medullary shell is a spherical lattice connected to polar spines by rods.

Remarks.—The internal structure of the medullary shell could not be determined, and it is not known if there is an internal spicule. The presence of such a spicule would place this taxon within Entactiniidae Riedel, 1967. Until the nature of the internal structure is determined, this taxon remains as *incertae sedis*. *Stylosphaera quasirobusta* Aberdeen, 1940 may be synonymous with this taxon, yet there is insufficient morphologic detail preserved in the Aberdeen's syntype to make a positive determination.

Measurements.—See Table 30.

Type locality.—Payne Hills, Marathon uplift, west Texas.

Etymology.—(L.) *magnus* = large, *spina* = spine.

Designation of types.—Holotype USNM 466313, paratype TMM 1852TX1.

Range and occurrence.—Late Silurian, Zone 4, Marathon uplift, west Texas; Osobudani Valley, central Japan.

Spumellarian indet. sp. A
Plate 5, figure 1

Description.—Latticed cortical shell with three, possibly four, robust triradiate bladed spines. Spines are tapered and sharp-ended. Rod-shaped primary bars attach spherical latticed medullary shell to cortical shell.

Remarks.—The wall structure of cortical and medullary shells is very similar to co-occurring species *Sty-*

Table 30.—Measurements (in μm) of *Stylosphaera* (?) *magnaspina*. Numbers of specimens measured are in parentheses.

	mean	mini- mum	maxi- mum	
diameter cortical shell	181	167	196	(6)
diameter medullary shell	98	88	112	(3)
avg. length primary spine	189	158	237	(5)
width spine base	69	60	74	(6)
total length	512	474	539	(3)

losphaera (?) *magnaspina*, n. sp. This suggests that these two may be related. No specimens were found where the inside of the medullary shell could be viewed. Further examination is necessary to determine the nature of shell construction.

Range and occurrence.—Late Silurian, upper Zone 3 through lower Zone 5 of the Marathon uplift, west Texas.

Spumellarian indet. sp. B
Plate 5, figures 8, 9

Description.—Spherical shell composed of loose, irregularly porous meshwork. Diameter of internal cavity is approximately 50% of shell diameter with shell wall thickness comprising the other 50%. Eight to ten short conical bladed spines occur irregularly on cortical shell. Bases of spine blades join with meshwork of cortical shell. Pores are large, rounded and are non-uniform in shape and size. Pore size between adjacent pores may differ by a factor of two.

Range and occurrence.—Silurian, Zone 2 and lower Zone 3 of the Marathon uplift, west Texas.

APPENDIX

Radiolarian Sample Descriptions

The precise location of the base of each measured section is given in Universal Transverse Mercator (UTM) coordinates and latitude/longitude coordinates. Intervals for each sample are given in meters above base of section. Sample numbers are laboratory numbers assigned when samples were processed for radiolarians. Sample numbers that are followed by a "c" are composite samples of two to four beds, commonly adjacent beds, within a 30 to 130 cm interval.

Section name: Payne Hills section

Topographic map: Beckwith Hills Quadrangle (7.5')

UTM: 13RFD57603975 = base of section, top of lower novaculite

Lat/Long: 30°10'50"N/103°21'47"W

General description: Located on the west limb of an upright south-plunging open syncline in the northwest region of the Payne Hills on the Paisano Ranch. Section dips steeply to the southeast. Caballos Novaculite is approximately 75 m thick with a thin (4 m) lower novaculite and a thin (8 m) upper novaculite. Lower chert and shale member is composed of laminated tan to gray weathering porcelanite, chert, and siliceous shale with beds ranging from 1 to 15 cm thick.

- 322c: Caballos Novaculite. Laminated tan siliceous mudstone alternating with medium gray chert beds 1–3 cm thick. Composite of 3 beds within 9.5–10 m
- 323c: Caballos Novaculite. Laminated tan to pale gray porcellanite/siliceous shale. Beds 2–3 cm thick. Composite of 3 beds within 13–13.5 m
- 324c: Caballos Novaculite. Tan laminated porcellanite. Composite of 3 beds within 16.5–17.5 m
- 325c: Caballos Novaculite. Tan and white chert. Porcellanite laminated. Beds 10 cm thick. Composite of 3 beds within 19–19.5 m
- 326c: Caballos Novaculite. Gray, tan, and white laminated chert/porcellanite with beds 8–15 cm thick. Composite of 2 beds within 21–21.7 m
- 327c: Caballos Novaculite. Gray, tan, and white laminated chert/porcellanite with beds 6–15 cm thick. Composite of 2 beds within 23.5–24 m
- 328: Caballos Novaculite. Gray, tan, and white laminated chert/porcellanite bed at 24.5 m
- 329: Caballos Novaculite. Gray, tan, and white laminated chert/porcellanite bed at 26.5 m
- 330: Caballos Novaculite. Gray, tan, and white laminated chert/porcellanite beds 6–15 cm thick. 2 beds within 28–28.3 m
- 331: Caballos Novaculite. Gray-white laminated chert bed at 29 m
- 332: Caballos Novaculite. Gray chert bed 5 cm thick at 31.5 m

Section name: Payne Hills II section (PH2)

Topographic map: Beckwith Hills Quadrangle (7.5')

UTM: 13RFD57263962 = base of section, lowest exposed bed of Caballos chert

Lat/Long: 30°10'69"N/103°21'00"W

General description: Section of Caballos Novaculite located at the top of the ridge to the east of the road at the pass through the Payne Hills on the Paisano Ranch. Base of Caballos Novaculite and top of underlying Maravillas Limestone is covered. The Caballos is approximately 70 m thick with no lower novaculite and a thin (3 m) upper novaculite. Lower chert and shale member as small thrust faults at the base.

- 077: Caballos Novaculite. Tan and brown laminated chert. Three beds sampled 1–2 cm thick, 70 cm above base of lowest exposed chert bed (70 cm above base of Caballos?). No novaculite is present in section.

Section name: Sulphur Springs

Topographic map: Rock House Gap quadrangle (7.5')

UTM: 13RFD54503289 = base of section, top of lower novaculite

Lat/Long: 30°07'07"N/103°21'00"W

General description: Section of west-dipping Caballos Novaculite in western basin margin near Sulphur Springs on the Roberts Ranch. Caballos section is approximately 90 m thick with a thin lower novaculite (6 m) and no upper novaculite. Top of novaculite is conglomeratic with the uppermost beds of white novaculite ripped up and plastically incorporated with granule-sized to cobble-sized lumpy black manganiferous chert. Some brecciation in black chert lumps with cavity infilling of orange ironstone. Lowermost exposed bed of lower chert and shale pinches and swells in what appears to be soft-sediment deformation. Lower chert and shale is tan to gray weathering laminated chert ranging from 2 cm to 15 cm thick. Pinch and swell beds occur throughout the section every few m that appear to be caused by soft sediment deformation.

- 386: Caballos Novaculite. Dark blue-gray glassy chert with opaque tan pinstripe laminations that pinches and swells. Bed 4 cm thick at 1.5 m
- 391c: Caballos Novaculite. Tan and blue-gray laminated chert and porcellanite. Composite of 3 beds within 12.5–13.5 m

Section name: McKnight (locality 9 of Fig. 0.1)

Topographic map: Marathon Quadrangle (7.5')

UTM: 13RFD72394365 = base of section, top of lower novaculite
Lat/Long: 30°12'53"N/130°12'33"W

General description: Section of Caballos Novaculite on a poorly exposed low-lying ridge on the northeast corner of the intersection between U.S. highways 90 and 385 on the McKnight Ranch. Lower novaculite is thick (24 m) and is overlain by a poorly exposed sequence of tan to gray weathering laminated chert and shale beds ranging from 6 cm to 30 cm thick. A 50 cm conglomeratic bed occurs approximately 1.5 m above the base of the lower chert and shale. Pinch and swell beds occur up section at 9 m above the base. Upper novaculite is absent.

- 430c: Caballos Novaculite. Laminated tan and gray chert beds. Composite within 3–4 m
- 431c: Caballos Novaculite. Laminated tan and gray chert. Composite within 5–5.5 m
- 432c: Caballos Novaculite. Laminated tan and gray chert. Composite within 7–7.5 m
- 434c: Caballos Novaculite. Laminated tan and blue-gray chert, 15–20 cm thick beds. Composite within 10.5–12 m
- 435c: Caballos Novaculite. Laminated tan and blue-gray chert, 15–20 cm thick beds. Composite within 14.3–15.5 m
- 436: Caballos Novaculite. White and tan laminated chert bed 20–30 cm thick at 17 m

Section name: Monument Creek (locality 7 of Fig 0.1)

Topographic map: Beckwith Hills Quadrangle (7.5')

UTM: 13RFD58623406 = base of section, top of lower novaculite
Lat/Long: 30°07'45"N/103°21'10"W

General description: South to southeast-dipping section of Caballos Novaculite approximately 125 m thick exposed along a ridge running northwest of Road Canyon. Section was measured on a slope along the south side of an intermittent stream drainage. The exposed section of Caballos Novaculite has a thick lower novaculite (38 m) and a thin upper novaculite (4 m). The lower chert and shale member consists of laminated thin-bedded greenish gray chert and porcellanite and olive siliceous mudstone with beds between 5 and 15 cm thick. Pale pink weathering siliceous shale occurs from 2.5 to 3 m above the top of the lower novaculite.

- 090: Caballos Novaculite. Dark gray and light green laminated chert bed 6–8 cm thick at 2 m
- 355: Caballos Novaculite. Olive green porcellanite bed 6 cm thick at 3.5 m
- 356: Caballos Novaculite. Two olive green porcellanite beds 7 cm thick at 5–5.2 m
- 357c: Caballos Novaculite. Green chert beds 12–15 cm thick. Composite 10–10.5 m
- 095: Caballos Novaculite. Gray-green porcellanite bed 6 cm thick at 11.8 m.
- 097: Caballos Novaculite. Green and white laminated chert beds 2 cm thick at 13.4 m
- 358: Caballos Novaculite. Green and tan banded chert beds 5 cm thick at 13.9–14 m
- 882: Caballos Novaculite. Green and tan laminated chert bed 2 cm thick at 14.3 m
- 359c: Caballos Novaculite. Green laminated chert bed 5 cm thick at 14.6 m

Section name: East Bourland (locality 11 of Fig. 0.1)

Topographic map: Simpson Springs Mountain Quadrangle (7.5')

UTM: 13RFD63142862 = base of section, top of lower novaculite
Lat/Long: 30°04'45"N/103°18'30"W

General description: West-dipping section of Caballos Novaculite

approximately 165 m thick on the west limb near the nose of a south-plunging anticline, East Bourland Mountain, on the Paisano Ranch. Lower novaculite is thick (26 m) and the upper novaculite is absent. Lower chert and shale member consists of laminated dark gray to tan weathering chert and porcellanite ranging from 2 to 10 cm thick. The lower few meters are bluish gray.

- 212c: Caballos Novaculite. Gray-blue and green mottled chert 3–5 cm beds. Composite of 2 beds within 0–0.5 m
 213c: Caballos Novaculite. Gray-blue and green mottled chert 3–5 cm beds. Composite of 2 beds within 2–2.5 m
 214: Caballos Novaculite. Gray-blue and green mottled chert bed at 3.5 m
 215c: Caballos Novaculite. Gray and black laminated chert beds 4–8 cm thick. Composite of 2 beds within 5–5.5 m
 216c: Caballos Novaculite. Gray and black laminated chert beds 4–8 cm thick. Composite of 2 beds within 5.5–6 m
 217: Caballos Novaculite. Gray, tan, and black laminated chert and porcellanite bed at 6.5 m
 218: Caballos Novaculite. Gray, tan, and black laminated chert and porcellanite bed at 9 m
 219: Caballos Novaculite. Gray laminated chert at 11 m
 220: Caballos Novaculite. Gray, black, green, and tan chert beds 6–10 cm thick at 13.5 m
 223: Caballos Novaculite. Gray and green chert bed 8 cm thick at 17.6 m
 224: Caballos Novaculite. Black and and tan laminated bed 4 cm thick with tanish gray nodules at 18 m
 225: Caballos Novaculite. Two beds of laminated green, black, and tan chert 7–10 cm thick at 18.5–18.7 m
 226: Caballos Novaculite. Two beds of laminated green, black, and tan chert at 19.4–19.6 m
 227c: Caballos Novaculite. Two beds laminated green, dark gray, and tan chert at 20.5 and 21 m
 228: Caballos Novaculite. Laminated green, dark gray, and tan chert at 21.5 m

Section name: Wood Hollow (locality 16 of Fig. 0.1)

Topographic map: Pena Blanca Mountains Quadrangle (7.5')

UTM: 13RFD71463001 = base of section, top of lower novaculite
 Lat/Long: 30°05'26"N/103°13'25"W

General description: West-dipping near-vertical section of poorly exposed Caballos Novaculite on south side of the road by Wood Hollow Tank on the Paisano Ranch. Caballos Novaculite is approximately 80 m thick with a thin lower novaculite (7 m) and a thin upper novaculite (4 m). Lower chert and shale is a dark gray to greenish weathering laminated chert and porcellanite with beds ranging from 5 to 20 cm thick. Lower chert and shale member is barely exposed and in a flat area with nearly the same topographic relief as the road.

- 395c: Caballos Novaculite. Greenish blue and gray laminated chert beds 3–8 cm thick. Composite of 3 beds within 8–8.5 m
 396c: Caballos Novaculite. Greenish blue and gray laminated chert beds 3–8 cm thick. Composite of 3 beds within 8.5–9 m
 397: Caballos Novaculite. Two beds of greenish blue and medium gray laminated chert beds 3–8 cm thick at 9.4–9.6 m
 398: Caballos Novaculite. Two beds of greenish blue and medium gray laminated chert beds 3–8 cm thick at 9.7–9.8 m
 399: Caballos Novaculite. Greenish blue and medium gray laminated chert bed at 11 m
 400: Caballos Novaculite. Greenish blue and medium gray laminated chert bed at 11.6 m
 401: Caballos Novaculite. Greenish blue, medium gray, and black laminated chert bed at 12.5 m
 403: Caballos Novaculite. Greenish blue, medium gray, and black laminated chert bed at 13 m
 407c: Caballos Novaculite. Medium gray and black banded chert (bands 1–3 cm) bed at 14 m
 408c: Caballos Novaculite. Gray-green, and black banded chert beds. Composite within 14.5–15 m
 409c: Caballos Novaculite. Gray-green and black banded chert beds 7–13 cm thick. Composite within 15–15.5 m
 410: Caballos Novaculite. Gray-green and black banded chert beds 7–13 cm thick. Composite within 15.5–16 m
 411: Caballos Novaculite. Gray-green and black banded chert beds 7–13 cm thick. Composite within 18–18.5 m

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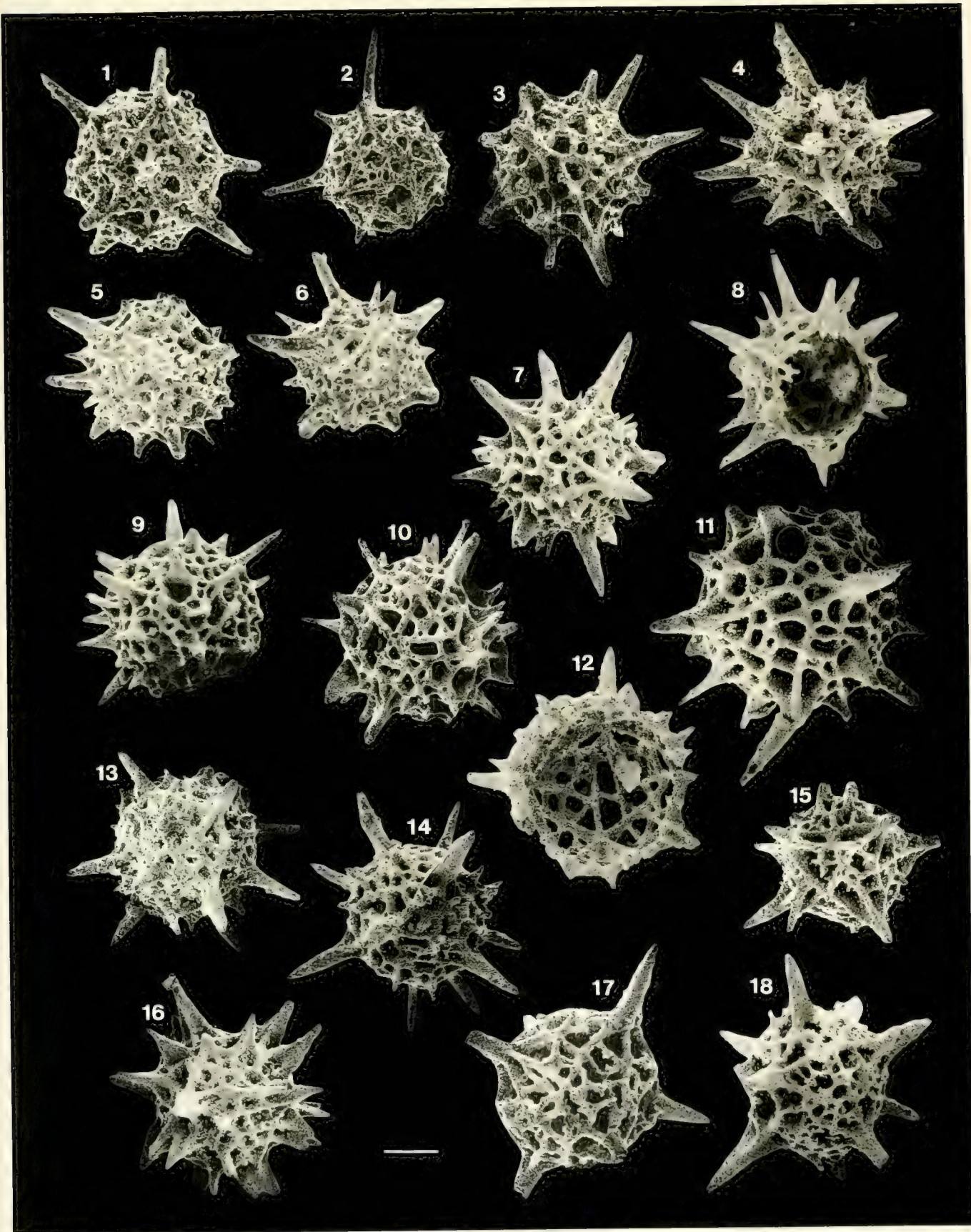
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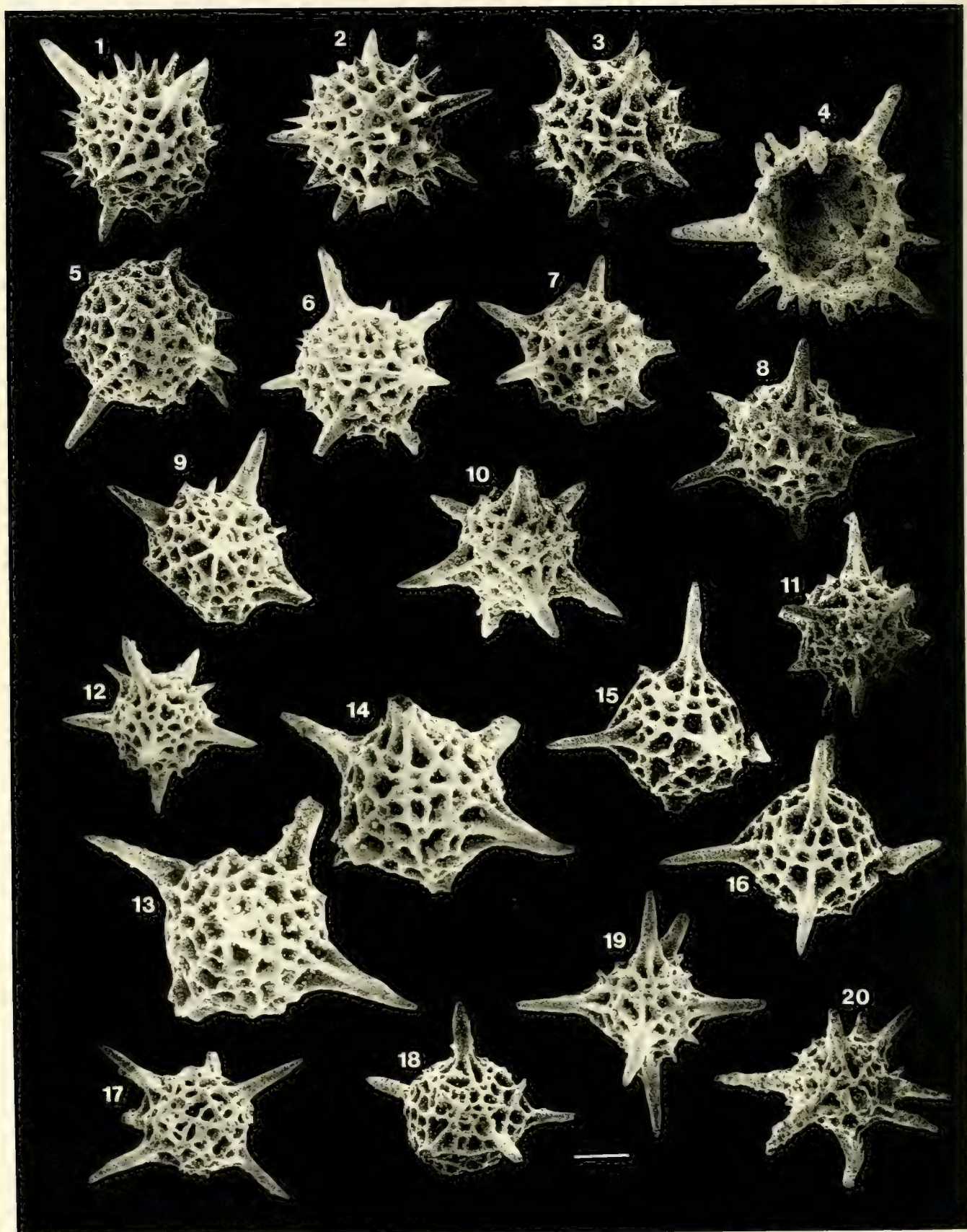
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EXPLANATION OF PLATE I

Scanning electron micrographs of Rotasphaeracea (Radiolaria) from the Caballos Novaculite, Marathon Basin, west Texas. The scale given after each figure corresponds to the scale bar in the lower left.

Figure	Page
1, 2. <i>Secuicollacta cassa</i> ?, Nazarov and Ormiston, 1984	23
1. Sample 213c, East Bourland Mountain, scale bar = 35 μ m.	
2. Sample 213c, East Bourland Mountain, scale bar = 50 μ m.	
3-8. <i>Secuicollacta solara</i> , new species	24
3. Sample 217, East Bourland Mountain, scale bar = 35 μ m.	
4. Sample 323c, Payne Hills, scale bar = 50 μ m.	
5, 6. Sample 215c, East Bourland Mountain, scale bar = 50 μ m.	
7. Holotype (USNM 466289), sample 325c, Payne Hills, scale bar = 50 μ m.	
8. Sample 326c, Payne Hills, scale bar = 50 μ m.	
9-12. <i>Secuicollacta foliaspinella</i> , new species	23
9. Sample 219, East Bourland Mountain, scale bar = 50 μ m.	
10. Holotype (USNM 466286), sample 326, Payne Hills, scale bar = 50 μ m.	
11, 12. Sample 325c, Payne Hills, scale bar = 35 μ m.	
13, 14. <i>Secuicollacta</i> sp.	39
13. Sample 326c, Payne Hills, scale bar = 35 μ m.	
14. Sample 325c, Payne Hills, scale bar = 50 μ m.	
15. <i>Secuicollacta</i> sp. A.	25
Sample 324c, Payne Hills, scale bar = 50 μ m.	
16. <i>Secuicollacta</i> (?) <i>platyspina</i> , new species	24
Holotype (USNM 466287), sample 219, East Bourland Mountain, scale bar = 50 μ m.	
17, 18. <i>Rotasphaera nuda</i> , new species	21
17. Holotype (USNM 466293), sample 216c, East Bourland Mountain, scale bar = 35 μ m.	
18. Sample 325c, Payne Hills, scale bar = 35 μ m.	





EXPLANATION OF PLATE 2

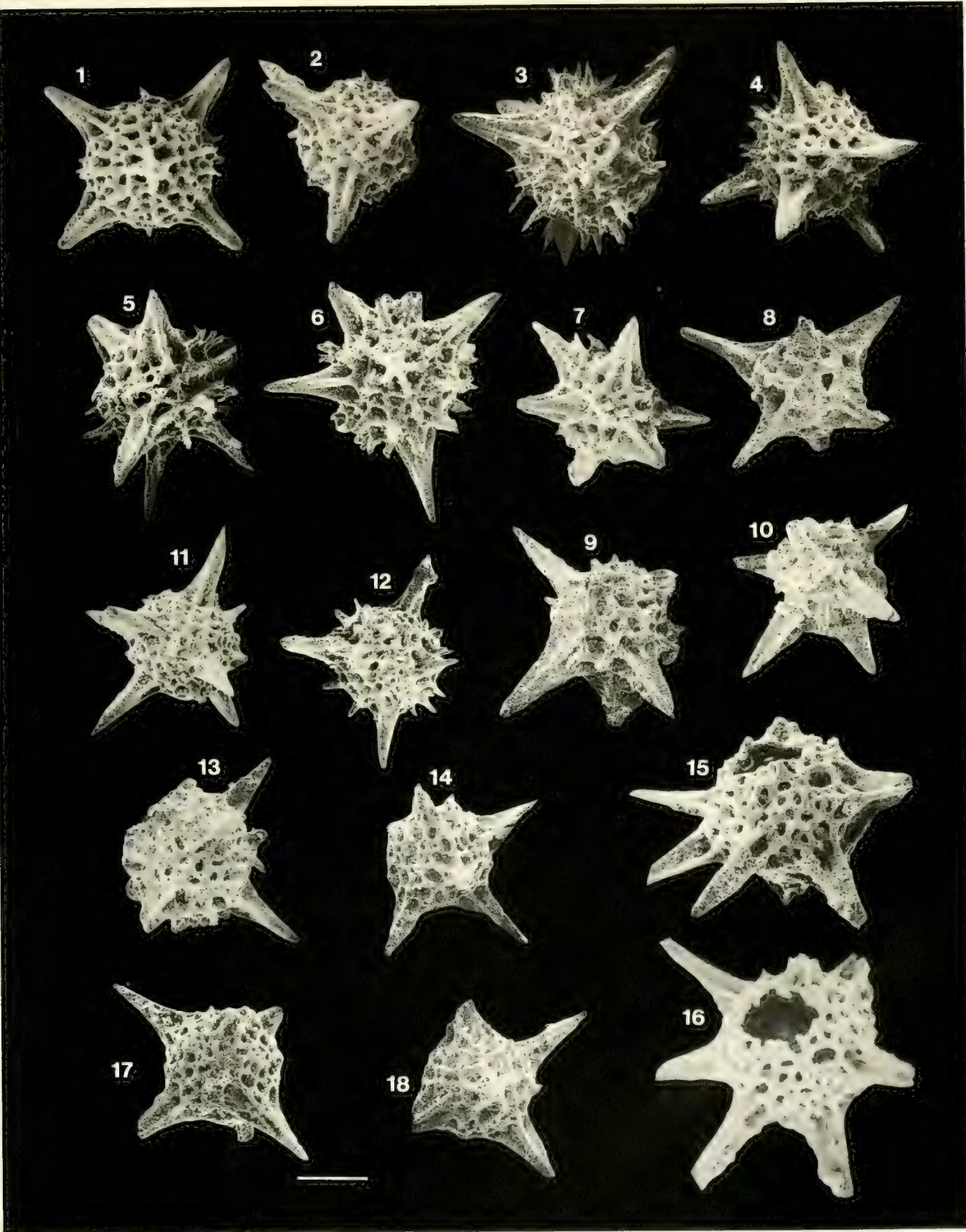
Scanning electron micrographs of Rotasphaeracea (Radiolaria) from the Caballos Novaculite, Marathon Basin, west Texas. The scale given after each figure corresponds to the scale bar in the lower right.

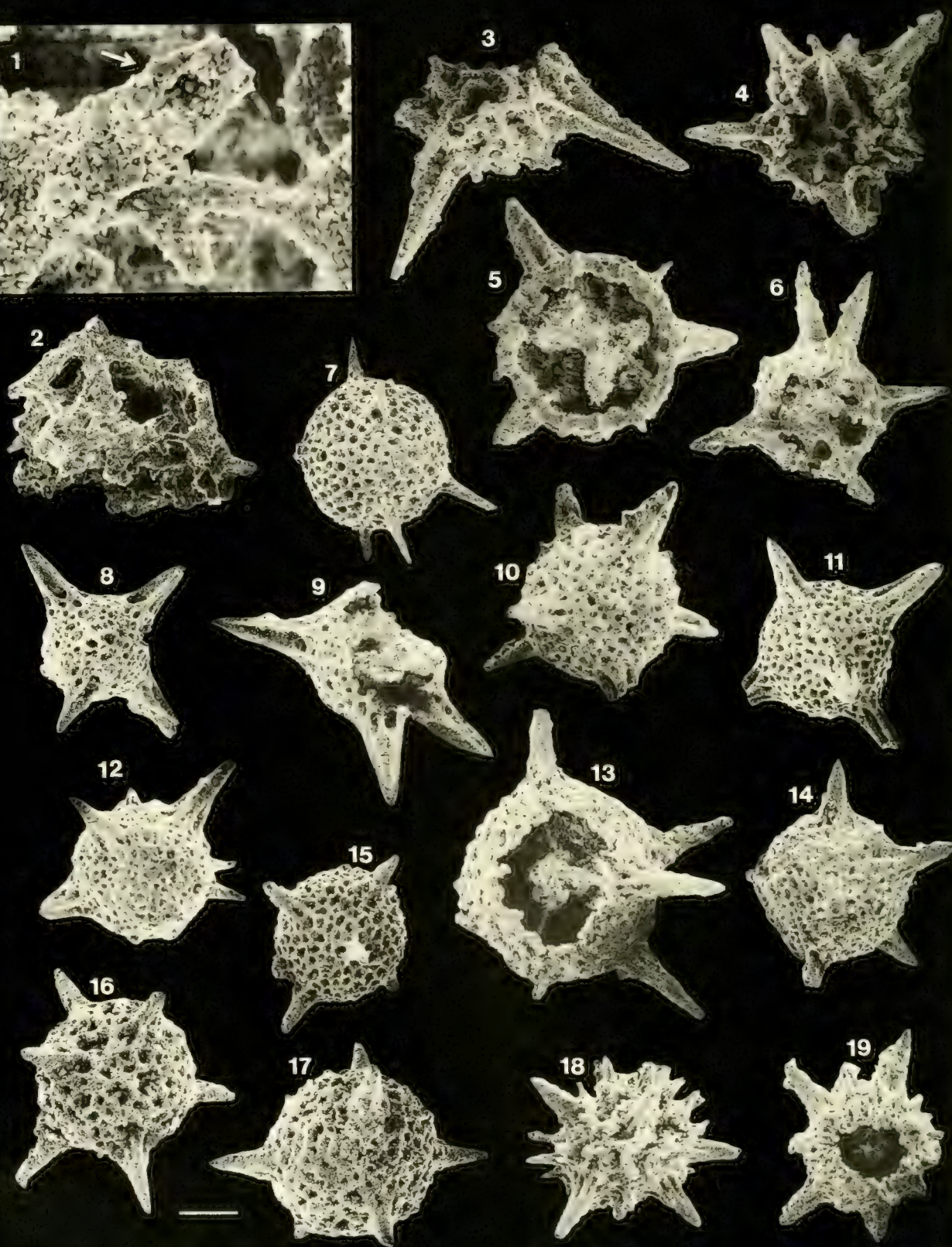
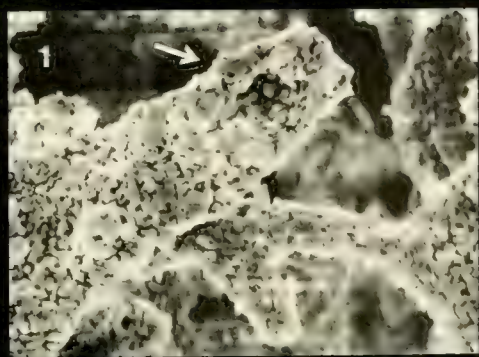
Figure		Page
1-4.	<i>Rotasphaera marathonsensis</i> , new species	21
1.	Holotype (USNM 466290), sample 326c, Payne Hills, scale bar = 50 μ m.	
2, 3.	Paratypes (TMM 1849TX3), sample 325c, Payne Hills, scale bar = 50 μ m.	
4.	Sample 326c, Payne Hills, scale bar = 50 μ m.	
5, 6.	<i>Rotasphaera robertsorum</i> , new species	22
5.	Holotype (USNM 466295), from sample 216c, East Bourland Mountain, scale bar = 50 μ m.	
6.	From sample 326c, Payne Hills, scale bar = 50 μ m.	
7-12.	<i>Rotasphaera beckwithensis</i> , new species	20
7, 10.	Sample 217, East Bourland Mountain, scale bar = 50 μ m.	
8.	Holotype (USNM 466291), sample 217, East Bourland Mountain, scale bar = 50 μ m.	
9.	Sample 324c, Payne Hills, scale bar = 50 μ m.	
11.	Sample 325c, Payne Hills, scale bar = 50 μ m.	
12.	Sample 327c, Payne Hills, scale bar = 50 μ m.	
13-16, 19, 20.	<i>Rotasphaera quadrata</i> , new species	21
13-16.	Paratypes (TMM 1844TX2), from sample 219, East Bourland Mountain, scale bar = 35 μ m. 13, 14 and 15, 16 are rotated views of two specimens.	
19.	Holotype (USNM 466294), from sample 219, East Bourland Mountain, scale bar = 50 μ m.	
20.	From sample 327c, Payne Hills, scale bar = 50 μ m.	
17, 18.	<i>Rotasphaera delicata</i> , new species	20
17.	Holotype (USNM 466292), sample 325c, Payne Hills, scale bar = 50 μ m.	
18.	Sample 219, East Bourland Mountain, scale bar = 50 μ m.	

EXPLANATION OF PLATE 3

Scanning electron micrographs of Spumellaria (Radiolaria) from the Caballos Novaculite, Marathon Basin, west Texas. The scale given after each figure corresponds to the scale bar in the lower left.

Figure	Page
1-4. <i>Pseudorotasphaera</i> (?) <i>robustispina</i> , new species	26
1, 2, 4. Paratypes (TMM 1849TX4), sample 325c, Payne Hills, scale bar = 50 μ m.	
3. Holotype (USNM 466299), sample 325c, Payne Hills, scale bar = 50 μ m.	
5-7. <i>Pseudorotasphaera</i> <i>hispida</i> , new species	25
5. Holotype (USNM 466296), sample 325c, Payne Hills, scale bar = 50 μ m.	
6. Sample 323c, Payne Hills, scale bar = 50 μ m.	
7. Sample 396c, Wood Hollow, scale bar = 50 μ m. Specimen 7 has poor preservation of secondary spines.	
8-10. <i>Pseudorotasphaera</i> <i>lanceolata</i> , new species	26
8, 10. Sample 395c, Wood Hollow, scale bar = 50 μ m.	
9. Holotype (USNM 466298), sample 395c, Wood Hollow, scale bar = 50 μ m.	
11, 12. <i>Pseudorotasphaera</i> (?) <i>rotunda</i> , new species	27
11. Holotype (USNM 466300), sample 326c, Payne Hills, scale bar = 50 μ m.	
12. Sample 325c, Payne Hills, scale bar = 50 μ m.	
13-18. <i>Pseudorotasphaera</i> <i>communa</i> , new species	26
13. Sample 216c, East Bourland Mountain, scale bar = 50 μ m.	
14. Sample 395c, scale bar = 50 μ m.	
15, 16. Rotated views of same specimen, sample 326c, Payne Hills, scale bar = 50 μ m.	
17. Paratype (TMM 1844TX3), sample 219, East Bourland Mountain, scale bar = 50 μ m.	
18. Holotype (USNM 466297), sample 219, East Bourland Mountain, scale bar = 50 μ m.	





EXPLANATION OF PLATE 4

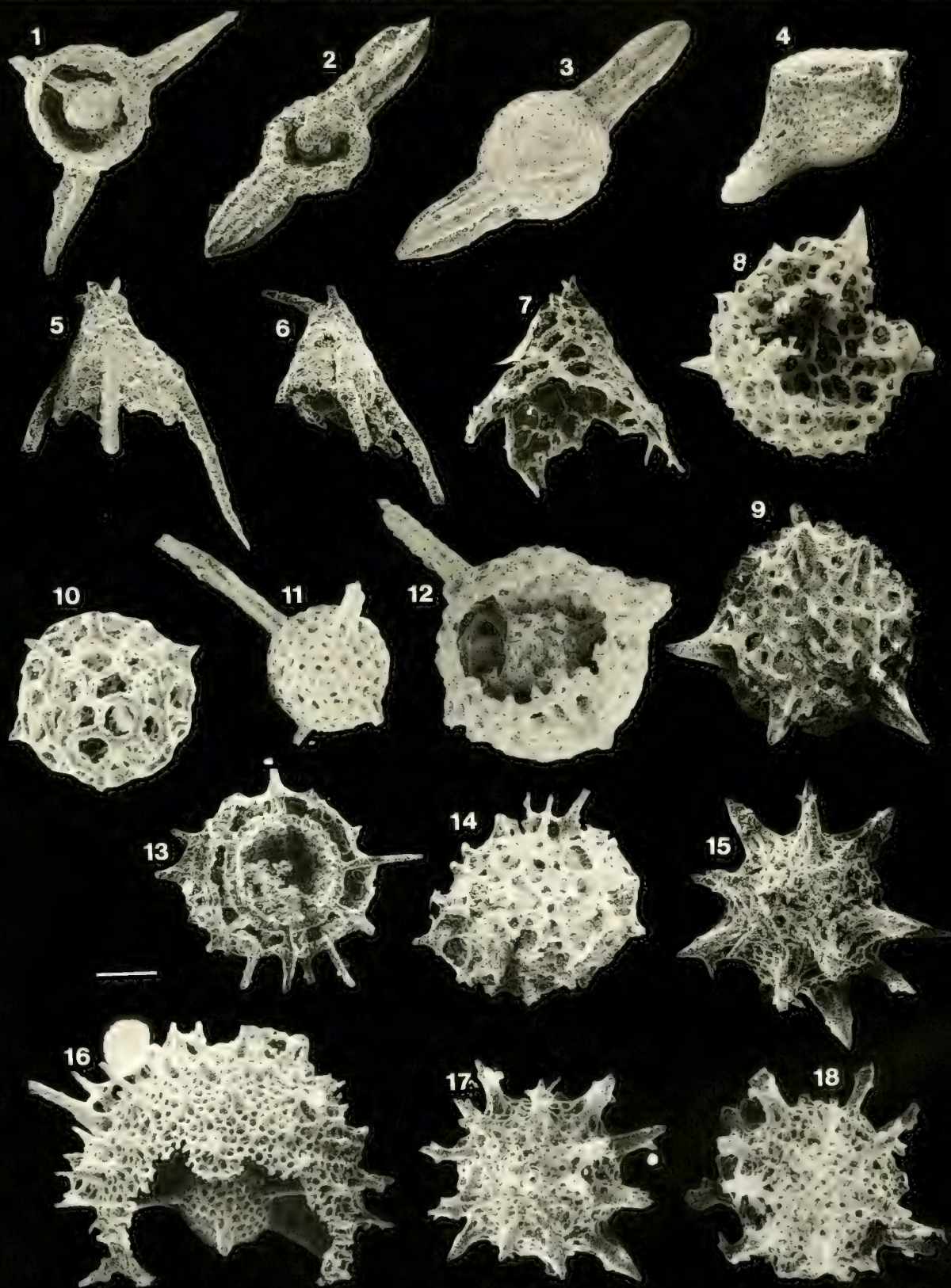
Scanning electron micrographs of Spumellaria (Radiolaria) from the Caballos Novaculite, Marathon Basin, west Texas. The scale given after each figure corresponds to the scale bar in the lower left.

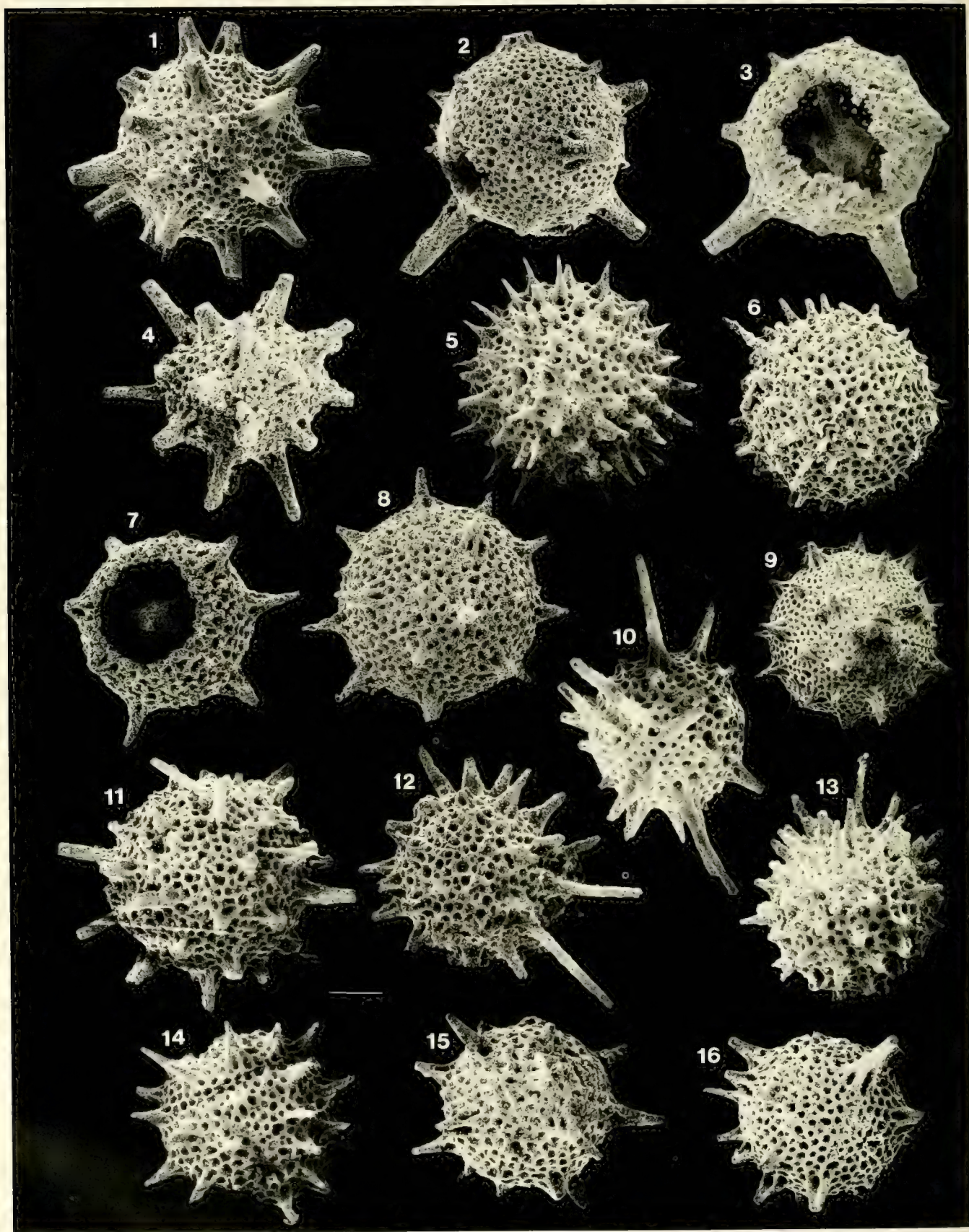
Figure	Page
1, 2. <i>Pseudorotasphaera</i> sp.	40
Sample 386, Rock House Gap. Fragment showing internal structure. Arrow points to hollow rod (primary bar) connecting to primary spine. Thinner solid rod (secondary bar) connects to cortex, but not to a primary spine. 1. Scale bar = 12 μ m. 2. Scale bar = 25 μ m.	
3, 4. <i>Pseudorotasphaera hispida</i> , new species.	25
Sample 395c, Wood Hollow. Fragments showing spinose nature of cortex. 3. Scale bar = 35 μ m. 4. Scale bar = 50 μ m.	
5. <i>Pseudorotasphaera</i> (?) <i>robustispina</i> , new species	26
Sample 325c, Payne Hills, scale bar = 35 μ m. Broken specimen with chalcedony infilling which obscures internal structure.	
6. <i>Pseudorotasphaera</i> sp.	41
Sample 395c, Wood Hollow, scale bar = 50 μ m. Broken specimen showing internal structure.	
7. <i>Palaeoactinosphaera</i> (?) <i>octaspina</i> , new species	35
Holotype (USNM 466214), sample 223, East Bourland Mountain, scale bar = 50 μ m.	
8, 9. <i>Palaeoactinosphaera barricki</i> , new species	34
8. Holotype (USNM 466307), sample 325c, Payne Hills, scale bar = 50 μ m.	
9. Sample 325c, Payne Hills, scale bar = 35 μ m. Note prominent collar grooves along spines. Base of grooves penetrate cortical shell at collar pores.	
10, 11. <i>Palaeoactinosphaera elegantissima</i> , new species.	35
10. Sample 326c, Payne Hills, scale bar = 50 μ m.	
11. Holotype (USNM 466309), sample 326c, Payne Hills, scale bar = 50 μ m.	
12-14. <i>Palaeoactinosphaera asymmetrica</i> , new species	34
12. Paratype (TMM 1842TX1), from sample 215c, East Bourland Mountain, scale bar = 50 μ m.	
13. Holotype (USNM 466306), from sample 322c, Payne Hills, scale bar = 50 μ m.	
14. Paratype (TMM 1841TX2), from sample 214, East Bourland Mountain, scale bar = 50 μ m.	
15-17. <i>Palaeoactinosphaera antica</i> , new species	33
15. From sample 223, Payne Hills, scale bar = 50 μ m.	
16. From sample 214, East Bourland Mountain, scale bar = 35 μ m.	
17. Holotype (USNM 466305), from sample 214, East Bourland Mountain, scale bar = 35 μ m.	
18, 19. <i>Stylactinosphaera prima</i> , new species	36
18. Holotype (USNM 466310), sample 322c, Payne Hills, scale bar = 88 μ m.	
19. Sample 322c, Payne Hills, scale bar = 88 μ m.	

EXPLANATION OF PLATE 5

Scanning electron micrographs of Spumellaria (Radiolaria) from the Caballos Novaculite, Marathon Basin, west Texas. The scale given after each figure corresponds to the scale bar in the lower left.

Figure	Page
1. Spumellarian indet. sp. A	39
Sample 328, Payne Hills, scale bar = 88 μ m.	
2-4. <i>Stylosphaera</i> (?) <i>magnaspina</i> , new species	38
Sample 328, Payne Hills, scale bar = 88 μ m.	
5, 6. <i>Goodbodium</i> sp.	37
Sample 215c, East Bourland Mountain, scale bar = 35 μ m.	
7. <i>Holdsworthum</i> sp.	37
Sample 326c, Payne Hills, scale bar = 50 μ m.	
8, 9. Spumellarian indet. sp. B	39
8. Sample 325c, Payne Hills, scale bar = 50 μ m.	
9. Sample 326c, Payne Hills, scale bar = 50 μ m.	
10. <i>Cenosphaera hexagonalis</i> Aberdeen, 1940	38
Sample 215c, East Bourland Mountain, scale bar = 50 μ m.	
11, 12. <i>Palaeoactinosphaera</i> (?) <i>crucispina</i> , new species	34
11. Holotype (USNM 466308), sample 322c, Payne Hills, scale bar = 88 μ m.	
12. Sample 322c, Payne Hills. Broken specimen showing internal structure. Note bladed primary bars, scale bar = 50 μ m.	
13, 14. Undescribed Spumellarian	41
Sample 223, East Bourland Mountain, scale bar = 50 μ m.	
15, 17, 18. <i>Fusalfanus osobudaniensis</i> Furutani, 1990	30
15, 17. From sample 325c, Payne Hills, scale bar = 50 μ m.	
18. From sample 213c, East Bourland Mountain, scale bar = 50 μ m.	
16. <i>Inanihella</i> sp. A	30
Sample 327c, Payne Hills, scale bar = 50 μ m. Note delicate remnants of delicate outer cortical shell.	





EXPLANATION OF PLATE 6

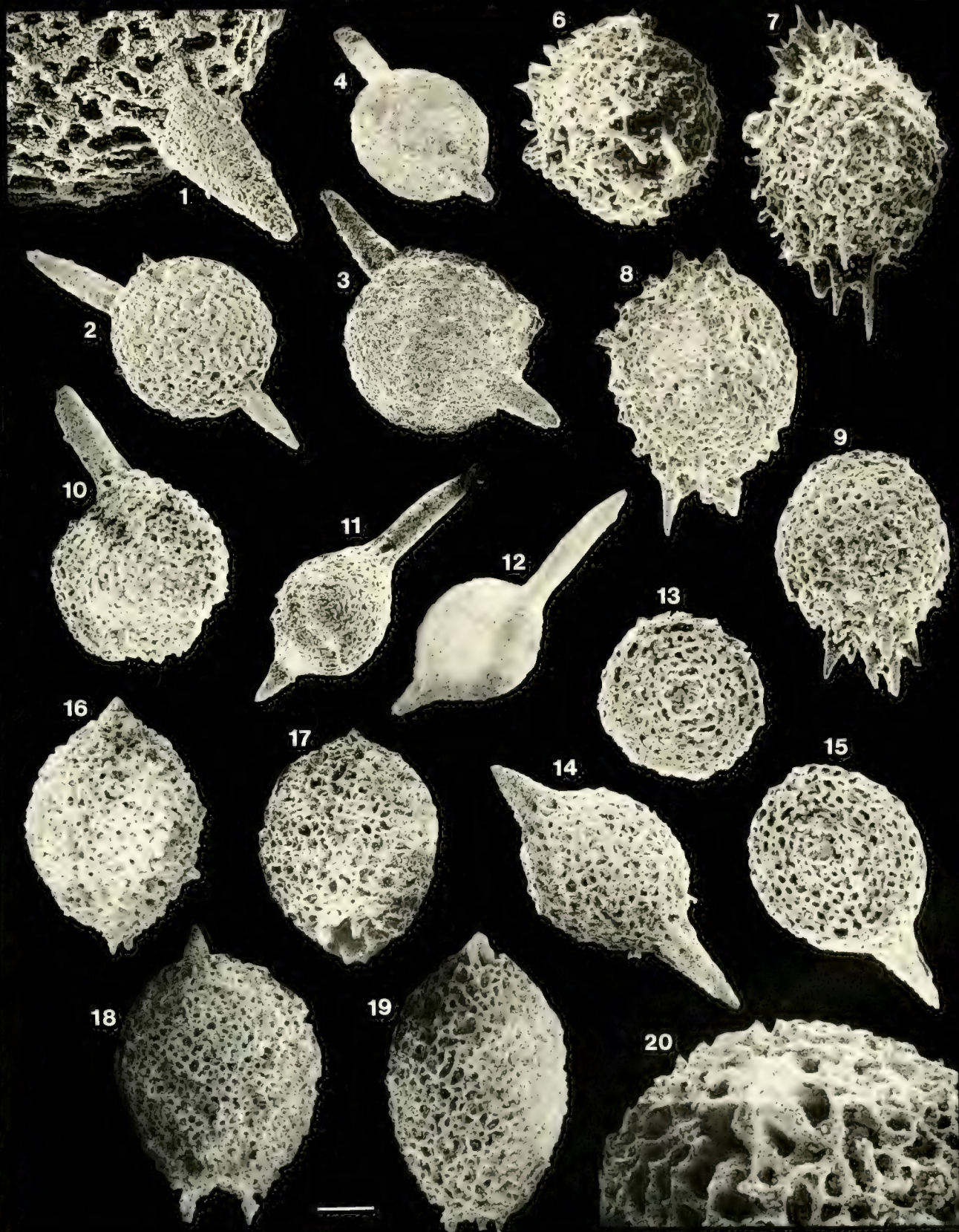
Scanning electron micrographs of Spumellaria (Radiolaria) from the Caballos Novaculite, Marathon Basin, west Texas. The scale given after each figure corresponds to the scale bar in the lower left.

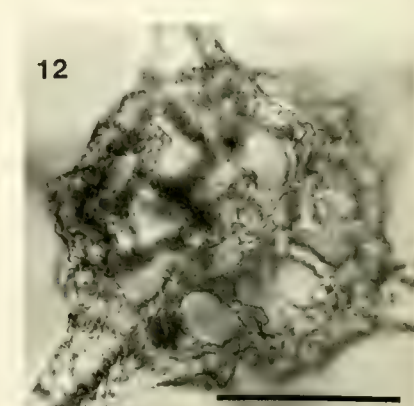
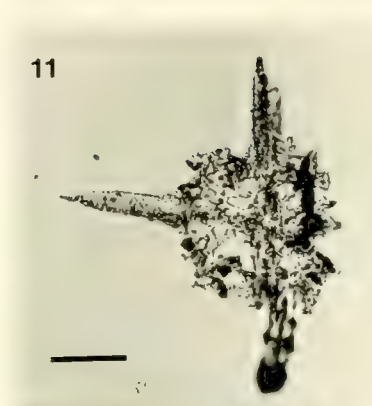
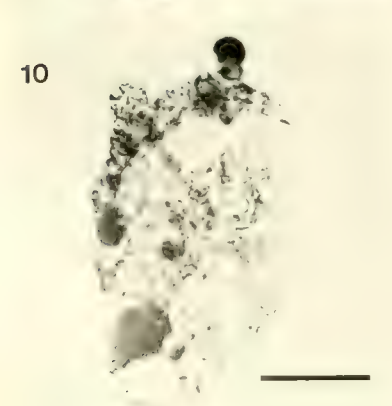
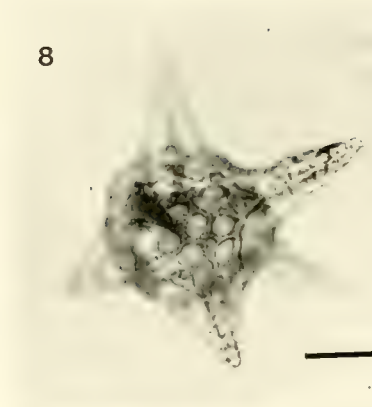
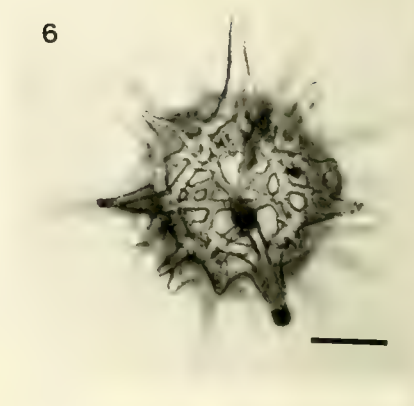
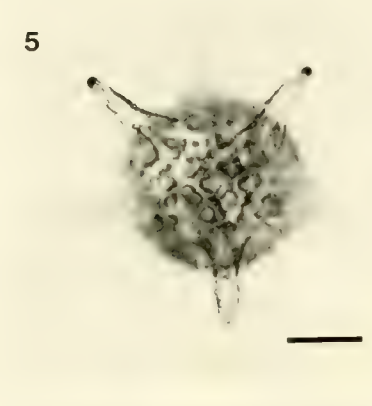
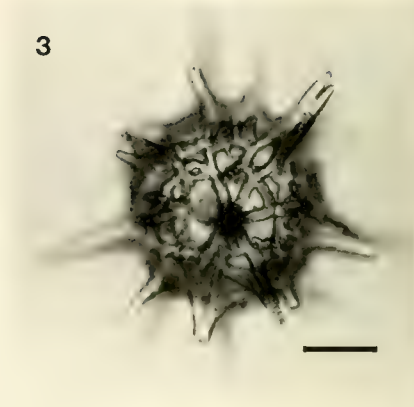
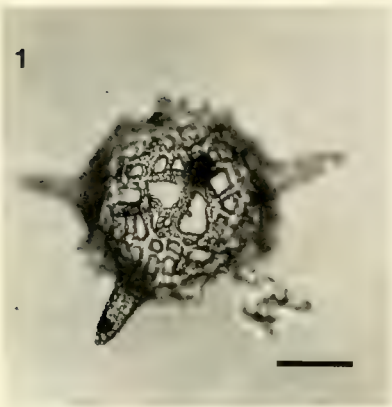
Figure	Page
1, 4. <i>Oriundogutta</i> (?) <i>kingi</i> , new species	31
1. Holotype (USNM 466302), sample 325c, Payne Hills, scale bar = 50 μ m.	
4. Sample 327c, Payne Hills, scale bar = 50 μ m.	
2, 3. <i>Oriundogutta</i> (?) <i>varispina</i> , new species	31
2. Holotype (USNM 466303), sample 8802, Monument Creek, scale bar = 50 μ m.	
3. Sample 8802, Monument Creek, scale bar = 50 μ m.	
5. <i>Zadrappolus</i> sp. aff. <i>spinosus</i>	32
Sample 219, East Bourland Mountain, scale bar = 50 μ m. Note tapered spines are shorter than <i>Z. spinosus</i> .	
6. <i>Zadrappolus spinosus</i> Furutani, 1990	32
Sample 326, Payne Hills, scale bar = 50 μ m.	
7, 8. <i>Zadrappolus lunaris</i> , new species	32
7. Paratype (TMM 1853TX1), sample 330, Payne Hills, scale bar = 50 μ m.	
8. Holotype (USNM 466304), sample 330, Payne Hills, scale bar = 50 μ m.	
9. <i>Zadrappolus</i> sp. A	32
Sample 326c, Payne Hills, scale bar = 88 μ m.	
10, 12, 13. <i>Zadrappolus tenuis</i> Furutani, 1990	32
Sample 223, East Bourland Mountain, scale bar = 50 μ m.	
11. <i>Zadrappolus</i> sp. aff. <i>tenuis</i> Furutani, 1990	32
Sample 324c, Payne Hills, scale bar = 50 μ m.	
14–16. <i>Zadrappolus yoshikiensis</i> Furutani, 1990	32
14, 15. Sample 325c, Payne Hills, scale bar = 50 μ m.	
16. Sample 327c, Payne Hills, scale bar = 50 μ m.	

EXPLANATION OF PLATE 7

Scanning electron micrographs of Spumellaria (Radiolaria) from the Caballos Novaculite, Marathon Basin, west Texas. The scale given after each figure corresponds to the scale bar in the lower left.

Figure	Page
1–4. <i>Praespongocoelia</i> (<i>Spongocoelia</i>) <i>parva</i> Furutani, 1990	38
1. Sample 215c, East Bourland Mountain, scale bar = 18 μ m.	
2, 3. Sample 215c, East Bourland Mountain, scale bar = 50 μ m.	
4. Sample 077, Payne Hills, scale bar = 88 μ m.	
6–9. <i>Bipylospongia</i> <i>rudosa</i> , new species	37
6, 7, 9. Paratype (TMM 1841TX3), sample 214, East Bourland Mountain, scale bar = 50 μ m.	
8. Holotype (USNM 466311), sample 214, East Bourland Mountain, scale bar = 50 μ m.	
10. <i>Praespongocoelia</i> sp.	40
Sample 077, Payne Hills, scale bar = 50 μ m. Fragment showing spongy cortical wall.	
11, 12. <i>Praespongocoelia</i> <i>fusiforma</i> , new species	38
11. Holotype (USNM 466312), sample 213c, East Bourland Mountain, scale bar = 50 μ m.	
12. Paratype (TMM 1855TX1), sample 396c, Wood Hollow, scale bar = 50 μ m.	
13–15. <i>Pseudospongoprimum</i> (?) <i>tauersi</i> , new species	28
13, 14. Sample 882, Monument Creek. Equatorial and polar sections showing multiple concentric spongy layering, scale bar = 50 μ m.	
15. Holotype (USNM 466301), sample 882, Monument Creek, scale bar = 50 μ m.	
16–20. <i>Devoniglansus</i> <i>unicus</i> Wakamatsu <i>et al.</i> , 1990	28
16. Sample 330, Payne Hills, scale bar = 50 μ m.	
17, 19, 20. Sample 330, Payne Hills. Same specimen, scale bar = 50 μ m (figs. 17 and 19), 18 μ m (fig. 20).	





EXPLANATION OF PLATE 8

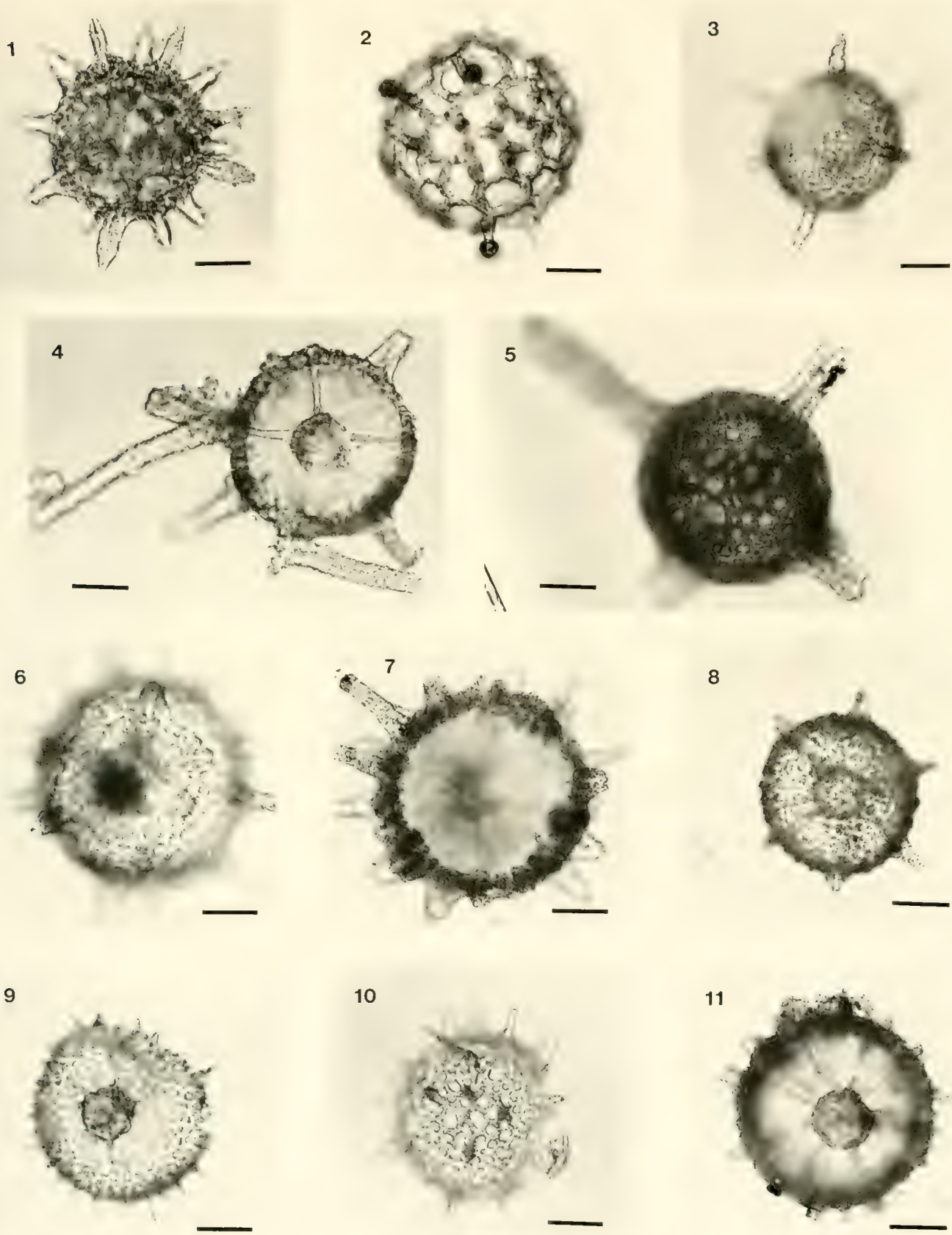
Transmitted light micrographs of Rotasphaeracea, all scale bars = 50 μ m.

Figure	Page
1, 2. <i>Rotasphaera marathonensis</i> , new species	21
1. Sample 328, Payne Hills, note open pore network and fine secondary spines.	
2. Sample 326c, Payne Hills.	
3, 6. <i>Secuicollacta solara</i> , new species	24
3. Sample 326c, Payne Hills. Note rotasphaerid structure with 6 primary rods.	
6. Sample 326c, Payne Hills.	
4, 5. <i>Rotasphaera beckwithensis</i> , new species	20
4. Sample 326c, Payne Hills. Note rotasphaerid structure with 6 primary rods and degree of tenting of primary spine bases.	
5. Sample 326c, Payne Hills. Focal plane is on cortical shell to illustrate pore structure.	
7. <i>Pseudorotasphaera lanceolata</i> , new species	26
Sample 395c, Wood Hollow. Note long thick-bladed spines. Cortical shell is less inflated than that of <i>P. communa</i> .	
8, 9, 12. <i>Pseudorotasphaera communa</i> , new species	26
8. Sample 213c, East Bourland Mountain. Focal plane on cortical wall showing pore structure.	
9. Sample 213c, East Bourland Mountain. Reversed side of specimen in fig. 8 showing internal structure.	
12. Sample 213c, East Bourland Mountain. Enlargement of fig. 9 showing close-up of internal structure.	
10, 11. <i>Pseudorotasphaera</i> sp.	41
Sample 395c, Wood Hollow. Fragments showing internal structure.	

EXPLANATION OF PLATE 9

Transmitted micrographs of non rotasphaerid spumellaria (Radiolaria) from the Caballos Novaculite, Marathon Basin, west Texas. Each scale bar = 50 μ m.

Figure	Page
1. <i>Fusalfanus osobudaniensis</i> Furutani, 1990	30
Sample 325c, East Bourland Mountain. Shell filled with microcrystalline quartz which obscures internal structure. Note spongy wall structure.	
2. <i>Cenosphaera hexagonalis</i> Aberdeen, 1940	38
Sample 326c, Payne Hills.	
3. <i>Palaeoactinosphaera</i> (?) <i>octaspina</i> , new species	35
Sample 223, Payne Hills.	
4. <i>Oriundogutta</i> (?) <i>varispina</i> , new species	31
Sample 435c, McKnight Ranch.	
5. <i>Palaeoactinosphaera</i> (?) <i>crucispina</i> , new species	34
Sample 322c, Payne Hills.	
6, 7. <i>Oriundogutta</i> spp.	??
Sample 330, Payne Hills.	
8. <i>Zadrappolus lunaris</i> , new species	32
Sample 330, Payne Hills.	
9, 11. <i>Zadrappolus spinosus</i> Furutani, 1990	32
Sample 223, East Bourland Mountain.	
10. <i>Zadrappolus</i> sp.	32
Sample 223, East Bourland Mountain.	



INDEX

Note: Page numbers are in light face; plate numbers are in bold face type.

- aberdeeneae*, *Cenosphaera* 38
Acanthosphaera macroacantha 31
amoenitas, *Secuicollacta* 23
antica, *Palaeoactinosphaera* 4, 33, 34, 36
Astroentactiniinae 27
asymmetrica, *Palaeoactinosphaera* 4, 13, 34, 36
Australia 6
- bakanasensis*, *Helioentactinia* 30
barricki, *Palaeoactinosphaera* 4, 13, 34, 35
basiporosus, *Hexastylus* 20
Beckwith Hills 20, 39, 40
beckwithensis, *Rotasphaera* 2, 8, 13, 14, 20, 21
Belodella sp. indet. 14
Belodella 14
Bipylospongia rudosa 7, 13, 37
Bipylospongia 7, 13, 14, 37
- Caballeros Novaculite 7–9, 11, 14, 39–41
 age of 14
 sample descriptions 39–41
Canadian Archipelago 6, 14, 19
 radiolarian taxa from 33, 37, 39
cassa?, *Secuicollacta* 1, 23
cassa, *Secuicollacta* 14, 19, 22, 23
Cenosphaera aberdeeneae 38
Cenosphaera hexagonalis 5, 9, 14, 17, 38, 39
Cenosphaera plutonis 38
Cenosphaera 5, 9, 14, 17, 37, 38, 39
chalcidony 11, 27, 14
Collar grooves 4, 18, 28, 38
Collar pores 4, 18, 28
conodonts 8, 14, 16, 28
Copicyntra 28
Copiellintra 28
corals 16
Cornwallis Island 14
crucispina, *Palaeoactinosphaera* (?) 5, 9, 13, 35
- Dagger Flat Anticlinorium 8, 9
Dapsilodus obliquicostatus 14
Dapsilodus praecipuus 14
Dapsilodus sparsus 14
delicata, *Rotasphaera* 2, 20, 21
Devonian, Late 6, 17, 38
Devonian, Middle 6, 16
Devoniglansus 7, 13, 14, 15, 16, 28, 29, 37
Devoniglansus unicus–*Pseudospongoprimum tauersi* Interval
 Zone 14
Devoniglansus unicus 7, 13, 14, 15, 16, 28, 29, 37
Dimple Limestone 7
- East Bourland Mountain
 type localities at 20, 21, 22, 24, 26, 34, 37, 38
 locality description 41
echinatum, ?*Palaeoephippium* ? cf. 23
elegantissima, *Palaeoactinosphaera* 4, 13, 34, 35
Entactinosphaera 16, 33, 36
- flammatum*, *Palaeoscenidium* 37
foliaspinella, *Secuicollacta* 1, 23, 24
Fukuji Area 15–17
 radiolarian taxa from 23, 25, 31, 32, 38
Fusalfanus osobudaniensis Assemblage 16
Fusalfanus osobudaniensis 5, 9, 13, 16, 30, 31
Fusalfanus 5, 9, 16, 17, 30, 31
fusiforma, *Praespongocoelia* 7, 16, 38
- Gifu Prefecture 15, 16
Goodbodium 5, 14, 15, 16, 37
- Haplentactiniidae 19, 23
Haymond Formation 7
Helioentactinia bakanasensis 30
hexagonalis, *Cenosphaera* 5, 9, 14, 17, 38, 39
Hexastylus basiporosus 20
hispida, *Pseudorotasphaera* 3, 4, 13, 25, 26, 27
hispida, *Stylosphaera* 39
Holdsworthum sp. A. 5, 37
Holdsworthum 5, 37
horrida, *Secuicollacta* sp. cf. *S.* 24
hydrofluoric acid etching 11
- Ichinotani Valley, Japan 11
Inanigutta 16, 29
Inaniguttidae 13, 29, 30, 33
Inanihella macroacantha 14, 30, 31
Inanihella sp. A 30
Inanihella tarangulica 31
Inanihella 5, 30, 31
Interval Zone, defined 12
- Kazakhstan 6, 14
 radiolarian taxa from 19, 23, 31
kingi, *Oriundogutta* (?) 6, 13, 14, 31
Kockelella absidata 14
Kurosegawa Tectonic Zone 15
 radiolarian taxa from 23, 28, 29, 39
- lanceolata*, *Pseudorotasphaera* 3, 8, 13, 26
Llandoverian 14, 16
Lowest-Occurrence Zone, defined 12
Ludlovian 13, 14, 16
lunaris, *Zadrappolus* 6, 7, 14, 32, 33
- macroacantha*, *Acanthosphaera* 31
macroacantha, *Inanihella* 14, 30, 31
magnaspina, *Stylosphaera* (?) 5, 13, 39
Marathon Basin 6, 22
Marathon uplift
 geology 6–9
 structural domains 7, 8
 radiolarian zones of 13, 14
marathonensis, *Rotasphaera* 2, 8, 13, 19, 20, 21, 27
Maravillas Limestone 8
McKnight,
 locality description 40

- Mississippian 6, 8
 Monument Creek 9, 14
 locality description 40
 type localities at 28, 38
 morphospecies 17, 18
- novaculite 8, 9
nuda, *Rotasphaera* 1, 20, 21
- octaspina*, *Palaeoactinosphaera* (?) 4, 9, 13, 14, 36
 Ordovician, Late 8, 18, 19
Oriundogutta (?) *kingi* 6, 13, 14, 31
Oriundogutta (?) *varispina* 6, 9, 14, 31
Oriundogutta ramificans 31
Oriundogutta 6, 9, 13, 30, 31
 Osobudani Valley, Japan 16
osobudaniensis, *Fusalfanus* 5, 9, 13, 16, 30, 31
 Ouachita orogenic belt 6
Ozarkodina eosteinhorrensis ? 14
- Palaeoactinomids 14, 33
Palaeoactinosphaera (?) *asymmetrica* Lowest-Occurrence Zone 13
- Palaeoactinosphaera* (?) *crucispina* 5, 9, 13, 35
Palaeoactinosphaera (?) *octaspina* 4, 9, 13, 14, 36, 36
Palaeoactinosphaera antica 4, 33, 34, 36
Palaeoactinosphaera asymmetrica 4, 13, 34, 36
Palaeoactinosphaera barricki 4, 13, 34, 35
Palaeoactinosphaera elegantissima 4, 13, 34, 35
Palaeoactinosphaera 4, 5, 6, 33, 34, 35, 36
 Palaeoactinosphaeridae 18, 33, 36
Palaeoephippium ? cf. *echinatum* 23
 Palaeoscenediidae 37
Palaeoscenedium flammatum 37
 Palaeoscenediids 14
Paleosphaera 33
 Partial Range Zone, defined 12
parva, *Praespongocoelia* 7, 16, 38
 Payne Hills 9
 type localities from 20, 21, 24, 26, 27, 31, 32, 34, 35, 37, 39
 locality descriptions 39, 40
 Pena Blanca Mountains 41
 Pennsylvanian 6, 8
platyspina, *Secuicollacta* (?) 1, 20, 23, 24
plutonis, *Cenosphaera* 38
Praespongocoelia (*Spongocoelia*) *parva*–*Praespongocoelia* (*Spongocoelia*) *kamitakarensis* Assemblage 16
Praespongocoelia–*Stylosphaera* (?) *magnaspina* Partial Range Zone 13
Praespongocoelia fusiforma 7, 16, 38
Praespongocoelia parva 7, 16, 38
Praespongocoelia Taxon Range Zone 13
Praespongocoelia 7, 13, 14, 15, 16, 28, 37, 38
 pre-orogenic strata 6, 8
 Pridolian 13, 14, 16
prima, *Stylactinosphaera* 4, 13, 36, 37
 Primary rod, defined 18
 Primary spine unit, defined 18
 Pseudoaulophacilae 27
Pseudorotasphaera (?) *robustispina* 3, 4, 13, 27
Pseudorotasphaera (?) *rotunda* 3, 13, 27
Pseudorotasphaera hispida 3, 4, 13, 25, 26, 27
Pseudorotasphaera lanceolata 3, 8, 13, 26
Pseudorotasphaera 3, 4, 8, 13, 14, 25, 27
- Pseudorotasphaeridae* 18, 19, 25
Pseudospongoprimum (?) *tauersi* 7, 14, 16, 28, 38
Pseudospongoprimum sagittatum Assemblage 15, 16
Pseudospongoprimum sagittatum 16, 28
Pseudospongoprimum tazukawaensis Assemblage 16
Pseudospongoprimum 7, 28
- quasirobusta*, *Stylosphaera* 39
- ramificans*, *Oriundogutta* 31
robertsorium, *Rotasphaera* 2, 20, 21, 22, 27
robustispina, *Pseudorotasphaera* (?) 3, 4, 13, 27
Rotasphaera beekwithensis 2, 8, 13, 14, 20, 21
Rotasphaera delicata 2, 20, 21
Rotasphaera marathonsensis 2, 8, 13, 19, 20, 21, 27
Rotasphaera nuda 1, 20, 21
Rotasphaera quadrata 2, 21, 22, 26
Rotasphaera robertsorium 2, 20, 21, 22, 27
Rotasphaera 1, 2, 8, 13, 14, 16, 19, 20, 23
Rotasphaera–*Devoniglans* *unicus* Partial Range Zone 13
Rotasphaera 13, 18, 19
Rotasphaerid morphotype A 21, 22
Rotasphaerid morphotype B 23
Rotasphaerid Superzone 9, 13
rotasphaerid structure 8, 18, 19, 25
Rotasphaeridae 18, 19, 23, 25, 33
rotasphaerids 14, 15, 16, 17, 18, 19, 22, 23
rotunda, *Pseudorotasphaera* (?) 3, 13, 27
- sagittatum*, *Pseudospongoprimum* 16, 28
 Santiago Member 9
 Secondary rod, defined 18
Secuicollacta (?) *platyspina* 1, 20, 23, 24
Secuicollacta ? *exquisita* Assemblage 15
Secuicollacta amoenitas 23
Secuicollacta cassa ? 1, 23
Secuicollacta cassa 14, 19, 22, 23
Secuicollacta foliaspinella 1, 23, 24
Secuicollacta solara 1, 8, 14, 23, 24, 25
Secuicollacta sp. A 1, 25
Secuicollacta sp. cf. *S. horrida* 24
Secuicollacta 1, 8, 15, 16, 18, 19, 20, 22, 23
 Simpson Springs Mountain 41
solara, *Secuicollacta* 1, 8, 14, 23, 24, 25
 Southern Urals 14
 radiolarian taxa from 19, 23, 31
 spiculitic chert 8
spinosus, *Zadrappolus* 6, 9, 14, 16, 32
Spongocoelia parvus (*Praespongocoelia parva*) 38
Spongocoelia sp. nova A 38
Spongocoelia 7, 16, 28, 32
 Spongodiscacea 27
 Sponguridae 27, 37
Spongurus 27
 Spumellarian indet. sp. A 5, 13, 39
 Spumellarian indet. sp. B 5, 39
Stylactinosphaera prima 4, 13, 36, 37
Stylactinosphaera 4, 33, 36
Stylosphaera (?) *magnaspina* Taxon Range Zone 13
Stylosphaera (?) *magnaspina* 5, 13, 39
Stylosphaera ? sp. A–*Stylosphaera* ? sp. B Assemblage 16
Stylosphaera ? sp. B 16, 17, 39
Stylosphaera ? sp. C Assemblage 17
Stylosphaera ? sp. C 17, 39

<i>Stylosphaera hispida</i>	39	<i>varispina, Oriundogutta</i> (?)	6, 9, 14, 31
<i>Stylosphaera quasirobusta</i>	39	<i>Walliserodus</i> sp. indet.	14
<i>Stylosphaera</i>	5, 37, 39	Wenlockian	14, 16
Sulphur Springs,		Wood Hollow,	
locality description	40	type localities at	26
syn-orogenic strata	6, 7, 8	locality description	41
<i>tarangulica, Inanihella</i>	31	<i>yoshikiensis, Zadrappolus</i>	6, 16, 32
<i>tauversi, Pseudospongoprimum</i> (?)	7, 14, 16, 28, 38	<i>Zadrappolus lunaris</i>	6, 7, 14, 32, 33
Taxon range zone, defined	12	<i>Zadrappolus</i> sp. A	6, 33
Tenting, defined	18	<i>Zadrappolus</i> sp. aff. <i>tenuis</i>	6, 32
<i>tenuis, Zadrappolus</i>	6, 13, 32	<i>Zadrappolus spinosus</i>	6, 9, 14, 16, 32
<i>tenuis, Zadrappolus</i> sp. aff.	6, 32	<i>Zadrappolus tenuis</i>	6, 13, 32
Tesnus Formation	7, 8	<i>Zadrappolus yoshikiensis</i> Assemblage	16
<i>Tetrentactinia barysphaera</i> – <i>Ceratoikiscum famenium</i> Zone ...	23	<i>Zadrappolus yoshikiensis</i>	6, 16, 32
trilobites	16	<i>Zadrappolus</i>	6, 9, 13, 14, 15, 16, 17, 32
<i>uadrata, Rotasphaera</i>	2, 21, 22, 26		
<i>udosa, Bipyllospongia</i>	7, 13, 37		
<i>unicus, Devoniglansus</i>	7, 13, 14, 15, 16, 28, 29, 37		

PREPARATION OF MANUSCRIPTS

Bulletins of American Paleontology usually comprises two or more separate papers in two volumes each year. The series is a publication outlet for significant, longer paleontological monographs (*i.e.*, more than approximately 50 printed pages), for which high quality photographic illustrations and the large quarto format are required.

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